

U.S. DEPARTMENT OF COMMERCE
National Technical Information Service

PB-260 021

BENEFITS EVALUATION
ARKANSAS-RED RIVER BASINS WATER
QUALITY CONSERVATION PROJECT

PUBLIC HEALTH SERVICE, DALLAS, TEXAS

AUGUST 1962

BIBLIOGRAPHIC DATA SHEET		1. Report No.	2.	3. Recipient's Accession No. PB-260 021	
4. Title and Subtitle Benefits Evaluation: Arkansas-Red River Basins Water Quality Project.				5. Report Date Aug 62	
7. Author(s)				6.	
9. Performing Organization Name and Address Public Health Service, Dallas, Tex. Region VII.				8. Performing Organization Rept. No.	
12. Sponsoring Organization Name and Address				10. Project/Task/Work Unit No.	
				11. Contract/Grant No.	
15. Supplementary Notes				13. Type of Report & Period Covered	
				14.	
16. Abstracts Those benefits ascribable to proposed works for controlling natural salt brine emissions are determined. The impact of stream quality improvements on municipal, industrial, and agricultural water uses in the Arkansas and Red River drainage basins is considered. Results of the study indicate that the improvement and preservation of water quality in the basins is essential to full utilization of the study area's surface water supply, which is expected to serve 22.4 million people by the year 2020. Water quality improvements attributable to the proposed control works will produce benefits to municipal and industrial uses in 13 subareas.					
17. Key Words and Document Analysis. 17a. Descriptors					
17b. Identifiers/Open-Ended Terms					
Arkansas River			Salt water intrusion		
Red River			Salinity		
*River basins			Water demand		
*Water quality data			Water supply		
*Water conservation			Industrial areas		
Brines			Municipalities		
17c. COSATI Field/Group 13B			Tables(Data)		
18. Availability Statement			19. Security Class (This Report) UNCLASSIFIED		21. No. of Pages 290
			20. Security Class (This Page) UNCLASSIFIED		22. Price \$9.25-3.00

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REPRODUCED BY
**NATIONAL TECHNICAL
INFORMATION SERVICE**
U. S. DEPARTMENT OF COMMERCE
SPRINGFIELD, VA. 22161

DEPARTMENT OF HEALTH, EDUCATION, AND WELFARE
Public Health Service, Region VII
Dallas, Texas

AUGUST 1962

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PREFACE

As the most abundant compound on the face of the earth, water may be looked upon as a plasma, essential to all forms of life and a basic tool in man's endeavors. Man is ever aware of the presence of water. His nature demands it. Water is consumed by all plant and animal life, requisite for sustaining human life. It is called on to serve as a carrier for foods in the canning and bottling industries, as a processing medium in the pulp and paper and chemical industries, as a source of energy in the power industry, as a cooling agent in the thermoelectric, petroleum refining, petrochemical, and primary metals industries, and as a quenching agent for fire protection. Water, with its many recreational opportunities, offers man a means of relaxation. As an air conditioner, it makes life more comfortable. Finally, its buoyant power provides, among other services, economical waterway transportation and a convenient method of waste disposal.

Supplying the increasingly complex water needs of our rapidly expanding population requires the availability of additional sources of supply. Many portions of the Nation, including much of the Arkansas and Red River drainage basins, are continually experiencing difficulty locating additional water supply. For these regions, extensive reuse of waters is not uncommon today, and as needs increase, intense reuse will be ever more common in the future.

This situation prompted President Kennedy's remark in his special Congressional message on natural resources:

"To meet all needs -- domestic, agricultural, industrial, recreational -- we shall have to use and reuse the same water, maintaining quality as well as quantity. In many areas of the country we need new sources of supply -- but in all areas we must protect the supplies we have."

To date, the main emphasis of water quality maintenance programs has been toward controlling manmade pollution. Federal, State, and local programs are attacking complex water pollution problems with such weapons as legislation, research, technical assistance, and grants. All these devices are aimed at preserving water quality for existing or potential downstream users. In almost all cases, however, quality targets are those set by natural circumstances.

The Arkansas-Red River Water Quality Conservation Project departs from this trend in a unique study to determine if the quality standards established by nature are irrevocable. This project will determine if waters of these two river basins can be made suitable for myriad present and future users. Waters of extended reaches of these streams are currently suitable only for limited use because of the far-reaching effects of natural brine emissions. The Public Health Service and the Corps of Engineers are engaged in this

cooperative study to (1) locate and evaluate sources of manmade and natural brine (2) design works to control natural emissions, and (3) determine benefits ascribable to brine control structures. As part of the overall study, the investigation herein reported assesses project benefits resulting from municipal, industrial, and agricultural water uses. Subsequent reports will be issued dealing with other aspects of the study.

I. INTRODUCTION

Authority

The Federal Water Pollution Control Act, Public Law 660 (84th Congress), states: "The Secretary shall, after careful investigation, and in cooperation with other Federal agencies, with State water pollution control agencies and interstate agencies, and with the municipalities and industries involved, prepare or develop comprehensive programs for eliminating or reducing the pollution of interstate waters and tributaries thereof and improving the sanitary condition of surface and underground waters."

Section 4(a) of the Act also states: "The Secretary shall conduct in the Department of Health, Education, and Welfare and encourage, cooperate with, and render assistance to other appropriate public (whether Federal, State, interstate, or local) authorities, agencies, and institutions, private agencies and institutions, and individuals in the conduct of, and promote the coordination of, research, investigations, experiments, demonstrations, and studies relating to the causes, control, and prevention of water pollution."

Under authority of the Federal Water Pollution Control Act, the Public Health Service, Division of Water Supply and Pollution Control, initiated the Arkansas-Red River Basins Water Quality Conservation Project, July 1, 1957.

In a resolution by the Committee on Public Works of the U.S. Senate, approved December 16, 1959, the U.S. Army Corps of Engineers was authorized to prepare a report with a view to determining, in cooperation with the Public Health Service, methods and means of improving and managing water quality in the Arkansas and Red River basins.

Subsequently, a plan of survey report entitled "CE-PHS Water Quality Study, Arkansas and Red River Basins" was drawn up in March 1960 and revised in December 1960. Under this plan, each agency is responsible for the preparation of a report covering its survey or studies. The basic duties as outlined are:

Public Health Service: (1) To outline the problem areas and select the sources of natural mineral pollution which are to be investigated, and (2) to determine the benefits which may be derived from the proposed improvement in water quality.

Corps of Engineers: To make studies of the engineering feasibility of structures which may be provided, or other means which may be devised, to eliminate or reduce the flow of salt brine from natural sources into the rivers and streams of the Arkansas and Red River basins.

In fulfillment of the second duty of the Public Health Service, the investigation reported herein was embarked upon in January 1961.

Purpose and Scope

This report is concerned with determination of those benefits ascribable to proposed works for controlling natural salt brine emissions. It deals with the impact of stream quality improvements, thus effected, on municipal, industrial, and agricultural water uses in the Arkansas and Red River Drainage basins.

Unlike other studies, stemming from the Water Supply Act of 1958 in which municipal and industrial (M & I) storage is related to the size (quantity) of the demand, this study, being concerned solely with the benefits ascribable to improvement in water quality, is somewhat unique. Therefore, the following basic assumptions and parameters were developed for use in this investigation.

1. Water demand projections shall include those expected to be exerted by municipalities, industries, and agriculture without quantity or quality limitations.
2. Water demands shall be projected for a definite time limit, the year 2020 (subsequently extended to the year 2070).

3. Chloride concentrations will be reduced in the main streams to less than 250 ppm with a desirable goal of 100 ppm set to assure maximum utility of waters.
4. Reduction of natural chlorides will provide a commensurate reduction in sodium loads, i.e., all natural chloride emissions enter solution as sodium chloride.
5. Effects of increased return waste flows on streams shall be considered in evaluating probable future concentration of water quality parameters.
6. Benefits derived from project works will be of an accumulative nature along the entire stream reach.
7. The least alternative cost doctrine shall be used to compute M & I benefits.
8. The difference in net return between irrigated agriculture and dryland farming in benefited stream reaches shall constitute agricultural benefits.
9. Benefits to other legitimate water uses such as fish and wildlife, flood control, navigation, etc., will be evaluated by the Corps of Engineers.

Acknowledgments

The assistance and cooperation of many persons and agencies is gratefully acknowledged. Special appreciation is due the following:

Private Industries and services

Aircraft Companies

Pulp and Paper Companies

Steel Companies

Petroleum Companies

Chemical Companies

Miscellaneous small industries

Consultants (water treatment, electric, and research)

Educational Institutions

Colleges and Universities

Federal Agencies

Federal Power Commission

U.S. Department of the Army

U.S. Department of Agriculture

U.S. Department of Commerce

U.S. Department of the Interior

U.S. Department of Labor

State Agencies

State Health Boards

State Water Resources Boards

State Water Pollution Control Boards

State Employment Services

Local Agencies

Chambers of Commerce

City Engineers

City Managers and Mayors

City Water Superintendents

Public Utility Companies

II. SUMMARY AND CONCLUSIONS

Summary

1. Poor quality water in some streams of the Arkansas and Red River basin has had a limiting effect on its usability. Waters of the main stems are used under controlled conditions by only two municipalities and for limited purposes by industry and agriculture. Mineral pollution, chiefly from brines, is attributed to natural and manmade sources.
2. Ninety-four percent of the natural pollution emanates from the 15 salt source areas under study by the Ark-Red River Basins Water Quality Conservation Project. Brine control works for these areas are currently being designed to eliminate up to 90 percent of the brine emissions.
3. To determine the effects of the quality control project an area slightly larger than the Ark-Red basin is studied. The study area, about 9 percent of the continental United States, covers all of Oklahoma and portions of seven surrounding States.
4. The 327 counties of the study area are grouped into 82 subareas to provide suitable size base areas for study, while maintaining a reasonable

degree of similarity in economic, water resource, and geographic factors. The 1960 population of this area totaled 9.3 million people. About one-half resided in 15 Standard Metropolitan Statistical Areas (SMSA).

5. Significant water using industries within the study area are: thermoelectric power generation, food processing, oil refining, natural gas processing, petrochemical manufacturing, pulp and paper manufacturing, iron and steel refining, and aluminum refining. All are adversely affected by high chloride concentrations in process waters.
6. Irrigation usage is the only large agricultural water demand in the study area adversely affected by high chloride concentrations.

Conclusions

1. The improvement and preservation of water quality in the Arkansas and Red River basins is essential to full utilization of the study area's surface water supply.

2. The study area population is projected to 24.5 million by the year 2020. Of these, 22.4 million are expected to be served by public water supply systems.
3. Projected municipal and industrial high quality water demands to the year 2020 are 5 billion gallons per day (bgd).
4. Projected cooling water industrial demands to the year 2020 are 2.4 bgd.
5. Irrigated acreage projected to the year 2020 totals 5½ million acres, requiring 9 million acre-feet of water annually.
6. With expected future increases in water utilization suitable mineral quality conditions can be maintained, following imposition of quality control programs.
7. Water quality improvements attributable to the proposed control works will produce benefits to municipal and industrial uses in 13 subareas. Projected (2020) water demands for these areas may be met by the following assumed plans:

	Demands in Excess of Present and/or Firmly Committed Sources	
<u>Demand Center</u>	<u>(mgd)</u>	<u>Project Source</u>
Tulsa	93	Keystone Reservoir
Oklahoma City	146	Keystone Reservoir
Duncan	15	Red River
Lawton	27	Red River
Ardmore	8	Lake Texoma
Poteau	25	Arkansas River
Wichita Falls	27	Lake Kemp
Gainesville	7	Red River
Dallas-Fort Worth	500	Lake Texoma
Van Buren	72	Arkansas River
Fort Smith	17	Arkansas River
Shreveport	100	Red River
Alexandria	40	Red River

8. Irrigated acreages benefited by the proposed quality control works total 40,000 acres distributed as follows:

<u>Area</u>	<u>Acreage</u>
S. E. Kansas-N. E. Oklahoma	10,000
E. Central Oklahoma	15,000
S. Central Oklahoma-N. Central Texas	15,000

9. Benefits for 2020 ascribed to proposed control of natural chloride pollution in the streams of the study area are:

<u>Municipal and Industrial Demand Center</u>	<u>1970 Worth of Average Annual Benefits (\$1,000)</u>
Tulsa	196
Oklahoma City	1,566
Duncan	421
Lawton	255
Ardmore	60
Poteau	37
Wichita Falls	378
Gainesville	96
Dallas-Fort Worth	2,089
Van Buren	105
Fort Smith	124
Shreveport	24
Alexandria	23
<u>Irrigation Area</u>	
S.E. Kansas-N.E. Oklahoma	28
E. Central Oklahoma	49
S. Central Oklahoma-N. Central Texas	62
	<u>5,513</u>

10. Study area projections to the year 2070 are:

Population = 42 million.

Municipal and industrial water demand (exclusive of cooling water) = 8.6 bgd.

Irrigation = no increase over 2020 acreages.

11. The 1970 worth of average annual benefits to water quality improvement for the year 2070 is \$10,565,000.

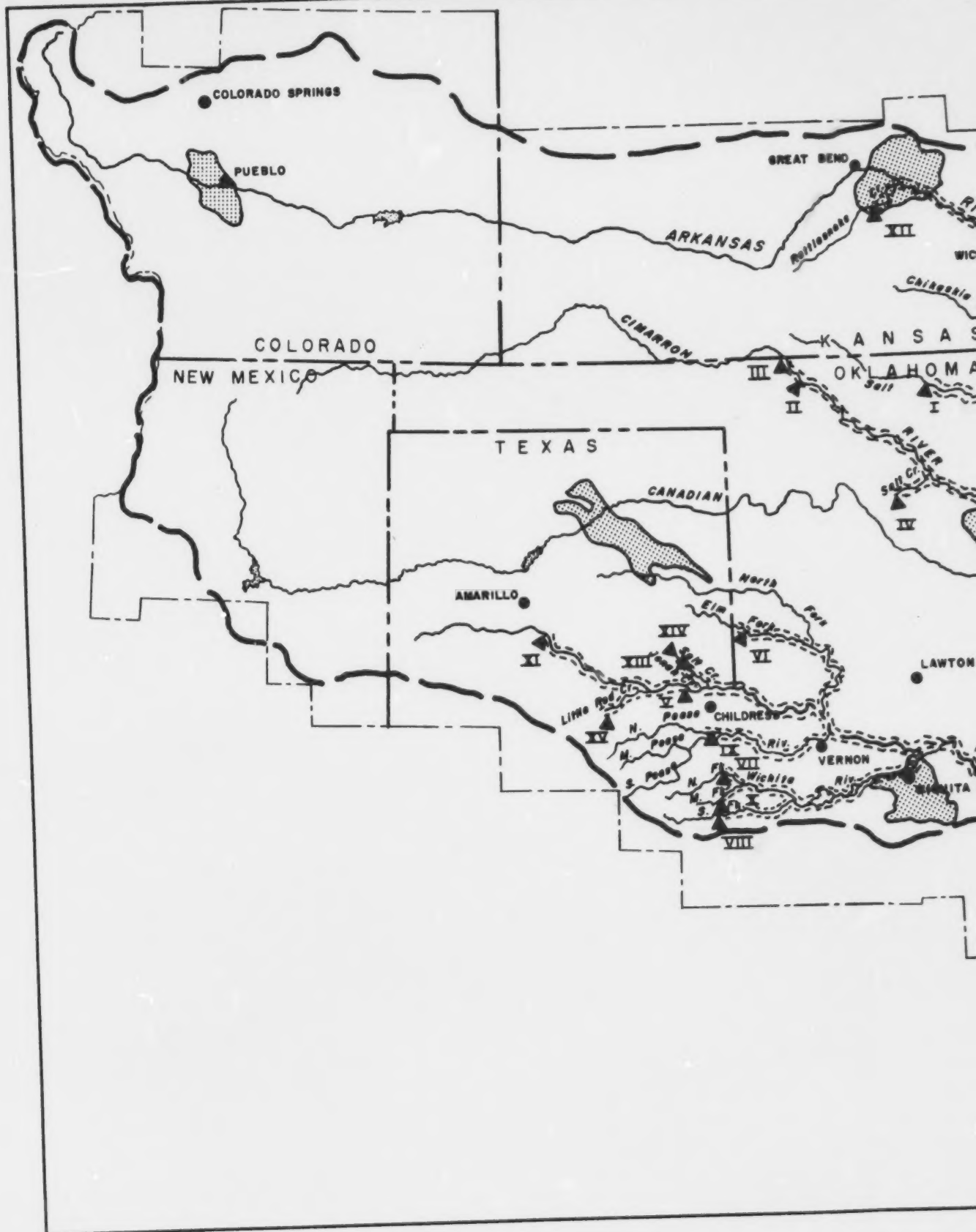
III. DESCRIPTION OF PROJECTS

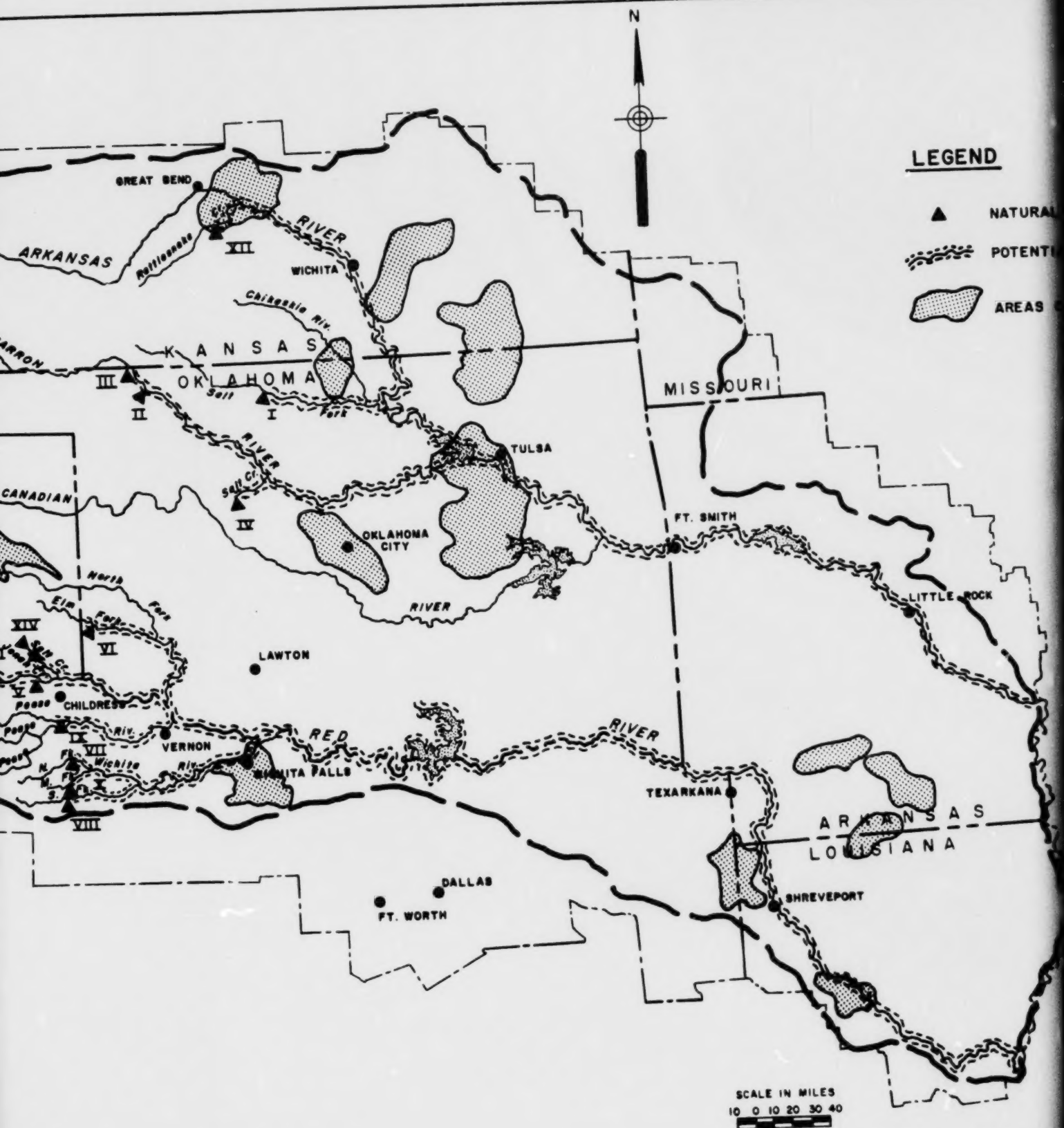
Sources of Pollution

Many streams of the Arkansas and Red River basins are polluted with high concentrations of dissolved minerals, except during short periods when runoff provides sufficient good quality water for dilution. Mineral pollution, chiefly salt brine, stems from both natural and manmade sources. Estimated average chloride ion loads in the Arkansas River at Fort Smith, Arkansas, are 14,500 tons/day and in the Red River at Texarkana, Texas, 4,000 tons/day.^{1/}

Location of the 15 major natural salt source areas under study in the Ark-Red Water Quality Conservation Project are presented in Figure III-1. All reaches of streams below any of these areas have been designated as potential benefit stream reaches for purposes of evaluating project benefits in this report.

As shown in Table III-1, latest estimates indicate an average of almost 9,300 tons of chloride ion per day is emitted from the 15 natural salt source areas. A general geologic study of these sources revealed large salt deposits of Permian age underlie the areas at depths of 200 feet, or less.^{2/} Under certain hydrologic conditions, ground water dissolves some of the salt and returns to the surface as springs or salt plains. The natural brine sources vary considerably in magnitude and areal extent. Flows vary from less than 1 gpm in the smaller seeps to 2,250 gpm in the largest spring. Some of the salt sources are well defined, while others are numerous small springs, or seeps, extending for miles along a stream.





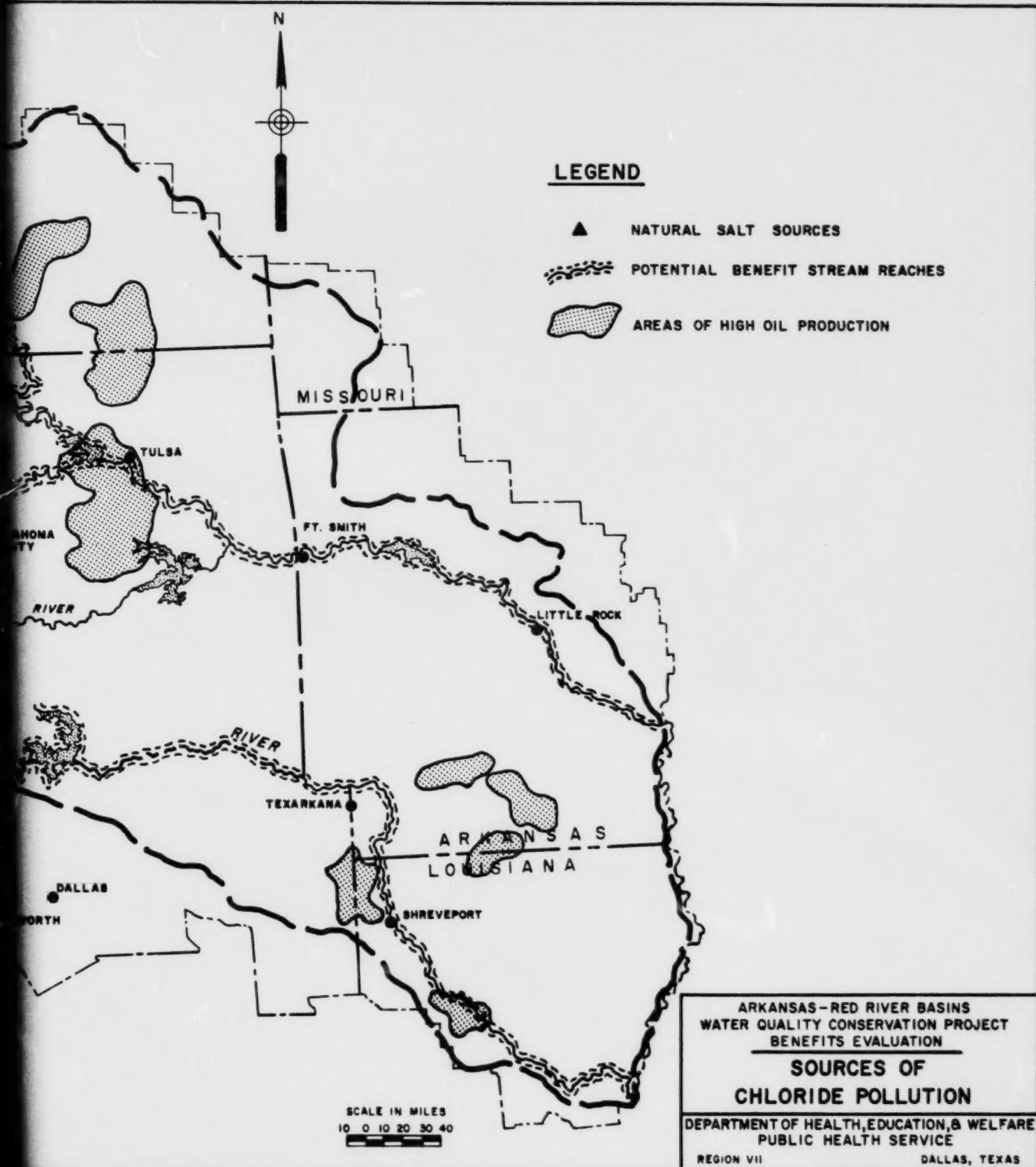


FIGURE III-1

Table III-1
Natural Salt Source Areas ^{1/}

<u>Area</u>	<u>Tributary Stream</u>	<u>Name and Location</u>	<u>Source</u>	<u>Estimated Chloride Load (T/D)</u>
<u>Red River</u>				
V	Prairie Dog Town Fork	Estelline Spring Hall Co., Texas	Large Spring	300
VI	North Fork	Elm Fork at Salton Crossing Harmon Co., Okla.	Springs & seeps	500
VII	Wichita R.	North Fork Cottle Co., Texas	Springs & seeps	150
VIII	Wichita R.	South Fork King Co., Texas	Springs	150
IX	Pease R.	North & Middle Forks Cottle Co., Texas	Seeps	300
X	Wichita R.	Middle Fork King Co., Texas	Seeps	50
XI	Prairie Dog Town Fork	Prairie Dog Town Fork Briscoe & Armstrong Co's., Texas	Seeps	200
XIII	Prairie Dog Town Fork	Jonah Creek Childress Co., Texas	Springs	300
XIV	Prairie Dog Town Fork	Salt Creek Childress Co., Texas	Seeps	150
XV	Prairie Dog Town Fork	Little Red R. Hall Co., Texas	Seeps	100
Subtotal				2,200

Table III-1 (Continued)

<u>Area</u>	<u>Tributary Stream</u>	<u>Name and Location</u>	<u>Source</u>	<u>Estimated Chloride Load (T/D)</u>
<u>Arkansas River</u>				
I	Salt Fork	Great Salt Plains Alfalfa Co., Okla.	Seeps	1,600
II	Cimarron R.	Big Salt Plains Harper, Woodward and Woods Co's., Okla.	Springs & seeps	5,000
III	Cimarron R.	Little Salt Plains Harper & Woods Co's., Okla.	Seeps	200
IV	Cimarron R.	Salt Creek Blaine Co., Okla.	Springs	120
XII	Rattlesnake Creek	Rattlesnake Creek Stafford Co., Kansas	Springs & seeps	150
Subtotal				7,070
Total				9,270

Much of the chloride pollution observed in the ground and surface waters of the study area originates from brines brought to the surface in oil well operations (see Figure III-1). In the early days of oil production, brine disposal methods consisted largely of storage in ponds where brines would seep away or be released to streams during periods when sufficient dilution water was available. In many cases, brine ponds were overtopped during heavy rains or were emptied into streams in anticipation of rains which failed to occur.

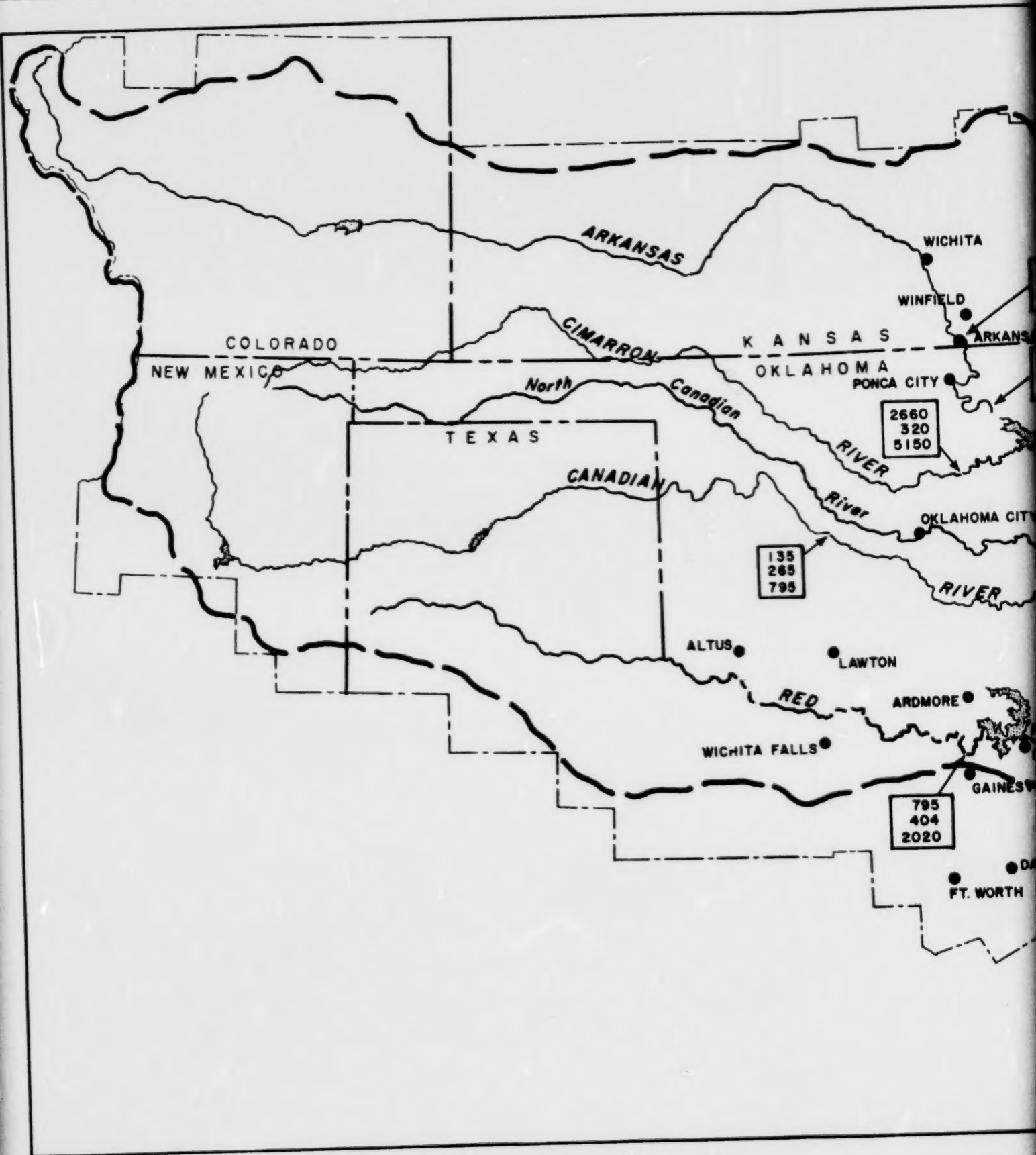
Present State water pollution control statutes, taking cognizance of the many shortcomings inherent in the brine pond disposal method, seek to correct such manmade pollution. Acceptable methods of disposal for oilfield brines are the aim of quality control programs in study area States. These programs have been particularly effective in Kansas, Oklahoma, and Texas.^{2/}

Other sources of manmade chloride pollution are attributable to waste discharges by municipalities and industries. Reduction of some industrial chloride pollution can also be expected by enforcement of State legislation, but it is doubtful that much can be done to alleviate salt pollution from municipalities.

Effect on Water Quality

Some retardation of the study area's population, industrial, and agricultural growth may be associated with the lack of suitable quality water in streams of the Arkansas and Red River basins.^{3/} Water quality in the potential benefit stream reaches is such that water is of limited usability. Figure III-2 shows the estimated average chloride, sulfate, and total dissolved solids concentrations in parts per million at significant points in the river systems. These concentrations are determined by averaging monthly means of analyses for the periods of record at these points. It should be noted that the Public Health Service recommends maximum chloride and sulfate concentrations of 250 ppm and total dissolved solids of 500 ppm in its drinking water standards.^{4/}

Large demand centers such as Wichita, Ponca City, Oklahoma City, Tulsa, Fort Smith, Little Rock, Wichita Falls, and Shreveport, have developed other sources of supply, because of the poor quality water in project streams. Metzler ^{5/} reported that Dallas residents bought drinking water in milk cartons during the drought in 1955-56 rather than use the highly mineralized supply which was partially obtained from the Red River near Gainesville, Texas. As water requirements increase, major demand centers will be forced to seek water of satisfactory quality at greater distances, and probably higher costs, unless waters of the project streams are upgraded in quality to the point of usability.



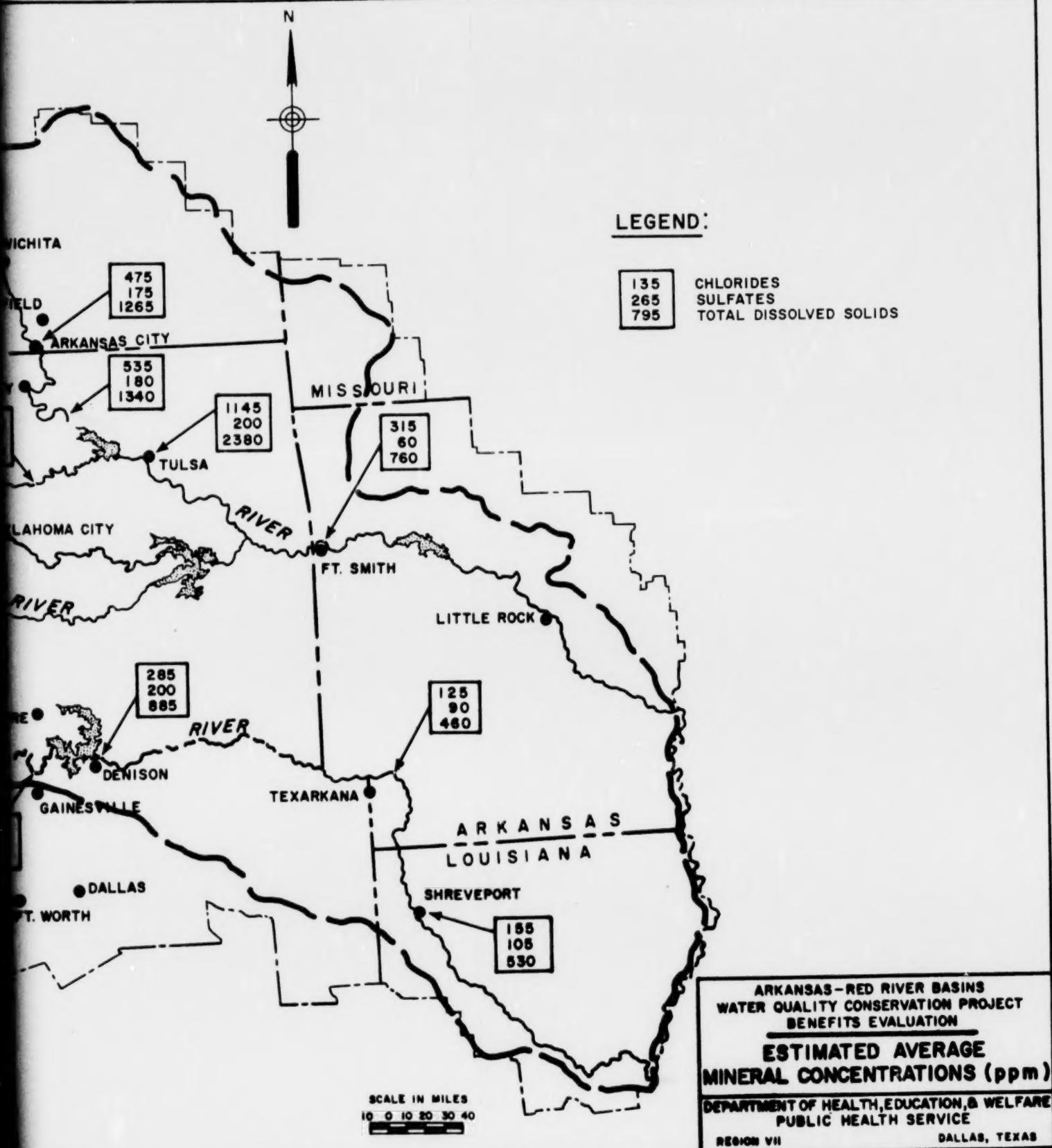


FIGURE III-2

Remedial Measures

Studies are now being carried on by the Corps of Engineers to evaluate the feasibility of several methods of alleviating natural brine pollution in the Arkansas and Red River systems. Some possible remedial measures now being considered are:

1. Collect fresh water streamflow above the salt emission areas and divert it to a point downstream by pipeline and/or open channel.
2. Construct ring levees around salt source areas to retard brine flow by equalizing the hydrostatic pressure.
3. Collect and pump salt water to an off-channel storage area for disposal through deep well injection.
4. Collect brine for conveyance through pipelines and/or open channels to ultimate disposal sites in the Gulf of Mexico.
5. Intercept fresh ground water before it becomes contaminated by salt.
6. Eliminate ground water by sealing the recharge area.

7. Provide fresh water channels in existing stream-beds through areas of brine emission.
8. Install layers of pervious granular material near the surface of salt plain areas to stop capillary action from raising brine to the surface.
9. Dilute brine with good quality water to reduce mineral concentration.

It is not expected that these remedial measures will reduce the pollution load by more than 90 percent at any of the salt source areas, because of the extent and complexity of the contributing areas. The Corps of Engineers is now testing the hydrostatic method at Estelline Springs and plans similar tests on springs discharging to the South Fork of the Wichita River near Guthrie, Texas.^{6/}

Bibliography - Chapter III

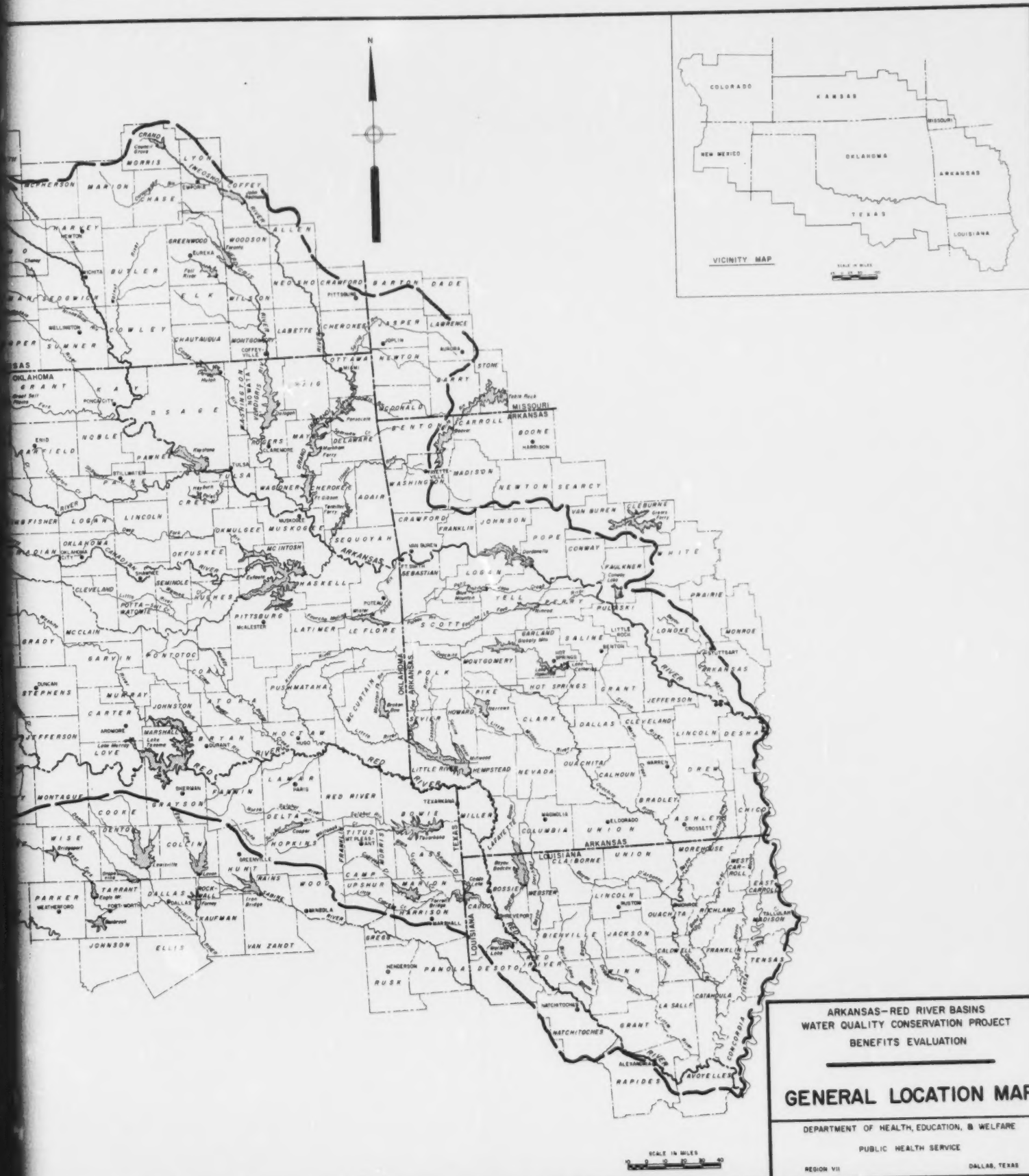
1. Preliminary estimates of chloride loads in tons/day agreed upon by the Public Health Service and Corps of Engineers, December 1961.
2. U.S. Department of Health, Education, and Welfare, Public Health Service, Arkansas-Red River Basins Water Quality Conservation Project. Aleck Alexander and W.C. Galegar, Comp. Dallas Texas, April 10, 1961.
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5. U.S. Department of Health, Education, and Welfare, Public Health Service, "Assessing the Water Pollution Problem." Dwight F. Metzler, comp., National Conference on Water Pollution. December 1960.
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IV. DESCRIPTION OF THE STUDY AREA

The benefit evaluation study area as shown on Figure IV-1 includes all of the Arkansas and Red River basins and a minor portion of the Missouri, White, Trinity, Brazos, and Sabine River basins. The study area consists of 327 counties in the southwestern and central plains region, including all of Oklahoma and a portion of Arkansas, Colorado, Kansas, Louisiana, Missouri, New Mexico, and Texas. Encompassed are a variety of geographical land forms, varying from the high rugged mountains of Colorado, over 10,000 feet in elevation; across the plains of Kansas, Oklahoma, and Texas, to the low-lying mountains and hilly terrain of the Ozark-Ouachita uplift; to the near sea level elevations of the coastal and alluvial flood plains where the Arkansas and Red Rivers approach the Mississippi River through the States of Arkansas and Louisiana.

Headwaters of the Arkansas River and its longest tributary, the Canadian, are in the Sangre de Cristo, Sawatch and Front Ranges of the Southern Rocky Mountains in Colorado and New Mexico. General mountain elevations here are between 8,000 and 10,000 feet above mean sea level with some peaks rising above 14,000 feet. East of the higher ranges, there is a piedmont and plains belt which extends from 50 to 100 miles and includes linear hills and valleys parallel with and close to the mountains. Farther east, moderately dissected plains and plateaus occur above which rise scattered volcanic peaks. Streams which flow through canyons and gorges at higher elevations emerge onto the adjoining plains as meandering rivers.





ARKANSAS-RED RIVER BASINS
WATER QUALITY CONSERVATION PROJECT
BENEFITS EVALUATION

GENERAL LOCATION MAP

DEPARTMENT OF HEALTH, EDUCATION, & WELFARE
PUBLIC HEALTH SERVICE

REGION VII

DALLAS, TEXAS

From eastern New Mexico and Colorado, the nearly unbroken surface of the High Plains extends for many miles. Outlying buttes and mesas dot the western border. Elevations diminish gradually from 5,000 feet to less than 2,500 feet at the eastern edge. The Arkansas, Cimarron, Canadian, and North Canadian Rivers flow generally eastward across the High Plains. The Red River rises in this area where most tributary streams have intermittent flows.

To the east the High Plains become more dissected by stream valleys and give way to the lowland prairie in central Kansas and east of the panhandle areas of Oklahoma and Texas. Elevations gradually decrease from about 2,000 feet to between 500 and 1,000 feet in eastern Kansas, Oklahoma, and Texas. The Arbuckle and Wichita Mountains in south-central and southwestern Oklahoma, the Flint Hills in southeastern Kansas, and the Sandstone Hills in eastern Oklahoma provide minor relief in the lowland prairie. Within these central lowlands, drainage courses become more numerous and streamflows increase notably.

In the central lowlands, the Verdigris and Grand (Neosho) Rivers contribute large flows to the main stem of the Arkansas River. Farther downstream the Ozark-Ouachita highlands in Arkansas, Missouri, and extreme eastern Oklahoma flank the Arkansas River. The Ozark Plateaus north of the Arkansas Valley and the Ouachita Mountains to the south are quite rugged with steep slopes and narrow valleys. Minor tributaries to the Arkansas River which rise in the Ozark-Ouachita highlands are swift flowing streams.

As the Red River emerges from the central lowland, it passes through the low and gently rolling Coastal Plain where elevations are generally less than 500 feet. The main stem of the River has a slight gradient and flows through an alluvial plain 2 to 12 miles wide. Numerous tributaries which rise in the southern Ouachita and the hilly areas to the west, including Boggy Creek, the Kiamichi River, and Little River, contribute to the substantially increased flows of the Red River in eastern Oklahoma and western Arkansas. The Ouachita River, the major downstream tributary, rises in the Ouachita Mountains and flows through the hilly uplands of southeastern Arkansas and the alluvial valley of the Mississippi River before entering the Red River just above its mouth.

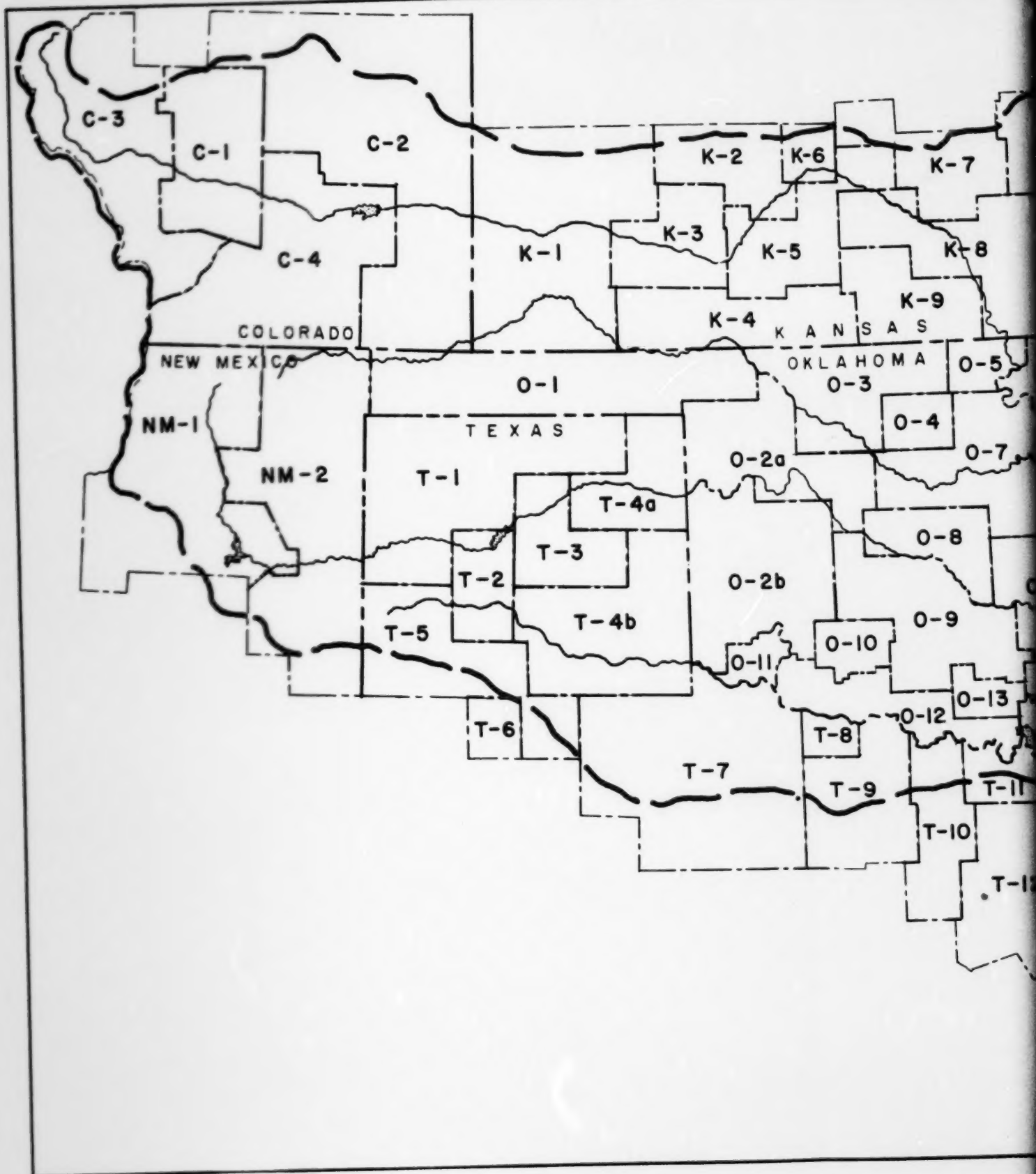
The lower Arkansas and Red Rivers meander through a wide belt of alluvial flood plains in eastern Arkansas and Louisiana. The alluvial plains are broken by occasional old riverbanks and stream terraces.

An area outside of the Arkansas-Red Rivers drainage basin is included in the benefit evaluation study area. This northern Texas area includes the upper reaches of the Brazos, Trinity, and Sabine Rivers in the lowland prairies and the coastal plains. The elevation ranges from 1,400 feet in the west to 200 feet in the east, and the surface features are similar to those of the Red River basin.

Thus, the principal surface features of the study area are: a relatively small extent of high mountains in the west, a large area of low mountains which rise abruptly from the Coastal and Mississippi Alluvial Plains in the east and, between the two mountain areas, a broad expanse of interior lowland sloping gradually from west to east, broken locally by escarpments, hills, and the relics of old, eroded mountains. Rivers with sources in areas of precipitous slope change from swiftly flowing to slow and sluggish streams meandering through wide alluvial valleys. During the extended draughts that are characteristic of the western half of the basin, only major rivers maintain continuous flows, while in the humid eastern lowlands, recurring floods frequently spread waters over wide expanses of adjacent lowlands.

A general location map of the study area is present in Figure IV-1. The map displays the location of the principal streams and reservoirs and the boundary of the Arkansas and Red Rivers drainage basin. Tributaries of importance to the investigation are also shown. Counties in the economic study area are located and named as well as cities used to reference subareas.

Counties are grouped into subareas as presented in Figure IV-2 to facilitate handling of data. Much of the data used in this report, such as population, employment, manufacturing, minerals, and agricultural, are recorded by counties. Dividing the 327 counties into smaller groups is advantageous in evaluating these data. Within the study area, a wide divergence of population density and economical,





ARKANSAS-RED RIVER BASINS
WATER QUALITY CONSERVATION PROJECT
BENEFITS EVALUATION

SUBAREAS

DEPARTMENT OF HEALTH, EDUCATION, & WELFARE
PUBLIC HEALTH SERVICE

REGION VII

DALLAS, TEXAS

FIGURE IV-2

mineralogical, climatological, and physiographical conditions exist which place different types of requirements on water. A grouping of counties by similar characteristic permits a more creditable projection of future water requirements.

The following criteria are considered in the selection of boundaries for subareas:

1. Population Characteristics: SMSA's and adjacent influenced counties are grouped (an SMSA is a county or group of contiguous counties which contain at least one city of 50,000 inhabitants or more). Counties are grouped into Population Centers which contain at least one county with a population of 30,000 or more and adjacent influenced counties. The remaining counties are grouped to provide a minimum 1960 total population of 20,000 and referred to as Rural.
2. Economic Characteristics: County groupings are selected on similar mineral resources or similar land resource areas.
3. Political and Natural Boundary Characteristics: Subareas are within a State. Subareas do not cross the drainage divide between the Arkansas and Red River basins.

The 82 subareas thus developed are described in Table IV-1 by Geographical, Climatological, and Economical Features.

Each subarea is designated by a code consisting of a letter and numeral for easy identification. The letter refers to the State in which the subarea is located and the numbering sequence is generally northwest to southeast. Further locational information is provided by a listing of counties within the subarea and its general location within the State. A municipality in each subarea is named as the Reference City. Subareas are classified as a Population Type, i.e., SMSA, Population Center, and Rural, as defined above.

The Geographical Features include tabulation of the Principal Streams, Land Areas and Natural Vegetation, Elevation, and Area. The Principal Streams listed are the major rivers in the subarea plus tributaries with drainage basins which constitute a major portion of the subarea. The Land Areas ^{1/} are regions having a combination of physical conditions that prevail generally and that differ in recognizable and significant ways from those of adjoining areas. The Natural Vegetation ^{1/} tabulation is a listing of the generalized native vegetative zones in a subarea. The general range in elevation above mean sea level (MSL) and the approximate surface area in square miles are given.

Under the Climatological Features are tabulated mean precipitation and temperatures for each subarea. The mean annual precipitation and the mean precipitation from April through September, the growing season, are presented. The mean annual temperature and the mean temperature for July and January, the warmest and coldest months, respectively, are presented.

The Economical Features are described by listing principal products of Agriculture, Mining, and Manufacturing. The listing of Agriculture products is by principal farm types. ^{2/} Products amounting to 50 percent or more of the value of all farm products sold are the basis for classification of farm types. General or miscellaneous farm types are not listed in the tabulation. The Mining products listed are a summary of the principal minerals of value mined in each county within the subarea from 1953 through 1959. ^{3/} The principal Manufacturing products listed are by the Standard Industrial Classification (SIC) designation. ^{4/} All manufacturing categories, except miscellaneous, with one or more plants of over 100 employees in a subarea are listed.

Table IV-1

Subarea Descriptions

Subarea Reference City Pop. Type Location	Counties	Geographical Features				Climatological Features			Economic Features		
		Principal Stream(s)	Land Areas & Natural Vegetation	Elev. Above MSL	Area (Square Miles)	Precip. (Mean in.) Annual	Temperature (Mean °F)		Agriculture	Principal Products	
						Apr.-Sep.	Annual	Jan. July		Mining	Manufacturing
C-1 <u>Pueblo</u> <u>Colo. Springs</u> SMA S.E. Colo.	Pueblo El Paso	Ark. R. Fountain Cr.	Rocky Mts., Brn. Plains, Plains of Up. Ark. R.; Plains Grass- lands, W. Pine, & N. Conif- erous Forest	4,500 to 8,000	4,554	12 9	52	29 76	Livestock Cash Grain Dairy	Clay Coal Uranium Ore Sand & Gravel Mica Yeldspar	Food & kin. Print. & pub. Stone, clay, & glass Prim. metals Fab. metals Lbr. & wood Mach., except electrical Elec. mach.
C-2 <u>Lamar</u> Rural S.E. Colo.	Elbert Lincoln Kit Carson Cheyenne Kiowa Prowers Baca	Ark. R. Big Sandy Cr.	Brn. Plains, Plains of Up. Ark. R.; Plains Grass- lands	3,500 to 6,200	14,343	15 12	54	31 78	Livestock Cash Grain	Sand & Gravel Stone	Not of Sig- nificance
C-3 <u>Canon City</u> Rural S.E. Colo.	Huerfano Custer Fremont Chaffee Lake Park Teller	Ark. R. S. Platte R.	Rocky Mts.; W. Pine, & N. Conif- erous Forest, S.W. Conif- erous Forest	5,000 to 14,400	8,047	23 11	35	18 55	Livestock	Lead & Zinc Gold Silver Copper Antimony Bismuth Cadmium Stone & Mica Shale Sand & Gravel Gypsum Coal	Stone, clay, & glass Prim. metals
C-4 <u>Trinidad</u> Rural S.E. Colo.	Las Animas Otero Crowley Bent	Ark. R. Purga- toire R.	Plains of Up. Ark. R.; Plains Grass- lands, W. Pine, & N. Conif- erous Forest, S.W. Conif- erous Forest	4,500 to 7,500	8,400	15 11	50	30 76	Livestock Cash Grain	Clay Coal Sand & Gravel Gypsum Stone Petro.	Food & kin.
MM-1 <u>Raton</u> Rural N.E. New Mexico	Colfax Mora San Miguel	Canadian R. Mora R.	High Plains, Rocky Mts., Cimarron & Canadian Breaks; Plains Grasslands, S.W. Conif- erous Forest, W. Pine, & N. Conif- erous Forest	5,000 to 12,000	10,546	15 11	48	28 69	Livestock	Coal Copper Silver Beryl Clay Sand & Gravel Columbium Tantalum	Apparel & related
MM-2 <u>Clovis</u> Pop. Cen. N.E. New Mexico	Union Harding Quay Curry	Cimarron R. N. Canadian R. Canadian R. Ute Cr.	High Plains, Cimarron & Canadian Breaks; Plains Grasslands, Prairie Grass- lands	5,000 to 6,500	10,299	17 12	53	33 73	Livestock Cash Grain	Sand & Gravel Stone Pumice	Not of Sig- nificance
K-1 <u>Garden City</u> Rural S.W. Kansas	Greeley Wichita Scott Lane Hamilton Keary Finney Stanton Grant Haskell Morton Stevens Seward	Ark. R. Cimarron R.	Brn. Plains, Loessial Out- wash Plains; Plains Grass- lands, Prairie Grasslands	2,500 to 3,800	9,969	18 14	55	30 79	Livestock Cash Grain	Nat. Gas Petro. Sand & Gravel Nat. Gas Liq.	Petro. & coal Chem. & allied
K-2 <u>Larned</u> Rural S.W. Kansas	Ness Rush Pawnee	Ark. R. Walnut Cr.	Bedrock Plains; Plains Grasslands, Prairie Grass- lands	1,900 to 2,600	2,540	21 16	55	30 80	Cash Grain Livestock	Petro. Nat. Gas Liq. Helium Sand & Gravel	Not of Sig- nificance
K-3 <u>Dodge City</u> Rural S.W. Kansas	Hodgeman Gray Ford	Ark. R.	Loessial Out- wash Plains; Plains Grass- lands, Prairie Grasslands	2,100 to 2,800	2,797	21 16	55	30 80	Cash Grain Livestock	Petro. Sand & Gravel Nat. Gas	Food & kin.

Table IV-1 (Continued)

Subarea Reference City Pop. Type Location		Subarea Descriptions					Climatological Features			Economic Features		
		Geographical Features					Precip. (Mean in.) Annual	Temperature (Mean °F)		Principal Products	Agriculture	Manufacturing
		Counties	Principal Stream(s)	Land Areas & Natural Vegetation	Elev. Above MSL	Area (Square Miles)		Apr.-Sep.	Annual			
K-4 <u>Medicine Lodge</u> Rural S.W. Kansas		Neade Clark Comanche Barber	Cimarron R. Salt Fork of Ark. R.	Red Plains; Plains Grass- lands, Prairie Grasslands	2,000 to 2,800	3,879	21 16	55	30 80	Livestock Cash Grains	Petro. Nat. Gas Liq. Sand & Gravel Pumice	Stone, clay, & glass
K-5 <u>Pratt</u> Rural S.W. Kansas		Edwards Kiowa Pratt Stafford Rice	Rattlesnake Cr. Ark. R.	Great Bend Sandy Plains; Plains Grass- lands, Prairie Grasslands	1,500 to 2,000	3,563	25 19	56	31 80	Cash Grains Livestock	Petro. Nat. Gas Salt Sand & Gravel Stone	Chem. & allied
K-6 <u>Great Bend</u> Pop. Cen. S. Cen. Kansas		Barton	Ark. R. Walnut Cr.	Great Bend Sandy Plains; Bedrock Plains; Prairie Grass- lands	1,700 to 2,000	892	25 19	56	31 80	Cash Grain Livestock	Petro. Nat. Gas Clay Sand & Gravel	Not of sig- nificance
K-7 <u>Newton</u> Rural S. Cen. Kansas		Ellsworth McPherson Marion Harvey	Smoky Hill R. Little Ark. R. Cottonwood R.	Great Bend Sandy Plains; Bedrock Plains; Prairie Grass- lands	1,200 to 1,800	3,117	29 22	57	32 81	Cash Grain Livestock Dairy	Salt Nat. Gas Petro. Sand & Gravel Stone	Petro. & coal Food & kin. Mach., except electrical Trans. equip.
K-8 <u>Wichita</u> SMA S. Cen. Kansas		Cowley Butler Sedgwick Reno	Walnut R. Minnescah R. Ark. R.	Great Bend Sandy Plains; Bluestem Hills; Prairie Grasslands	1,200 to 1,800	4,803	29 22	57	32 81	Cash Grain Livestock Dairy	Petro. Stone Nat. Gas Sand & Gravel Nat. Gas Liq.	Food & kin. Petro. & coal Stone, clay, & glass Fab. metals Print. & pub. Chem. & allied Mach., except electrical Trans. equip. Inst. & related Paper & allied
K-9 <u>Wellington</u> Rural S. Cen. Kansas		Sumner Harper Kingman	Minnescah R. Chikaskia R.	Great Bend Sandy Plains; Prairie Grass- lands	1,100 to 1,600	2,845	29 22	57	32 81	Cash Grain Livestock	Petro. Nat. Gas Sand & Gravel Stone	Not of sig- nificance
K-10 <u>Eureka</u> Rural S.E. Kansas		Chatauque Elk Greenwood Chase Morris	Cottonwood R. Grand (Neo- sho) R. Fall R. Verdigris R.	Bluestem Hills, Sand- stone Hills; Prairie Grass- lands	900 to 1,500	3,927	34 24	57	32 81	Livestock Cash Grain	Petro. Stone Nat. Gas Sand & Gravel	Not of sig- nificance
K-11 <u>Emporia</u> Rural S.E. Kansas		Lyon Coffey Woodson Allen Wilson Neosho Labette Cherokee	Verdigris R. Grand (Neo- sho) R.	Claypan Prai- ries; Prairie Grasslands	800 to 1,600	4,930	38 27	58	33 80	Livestock Cash Grain Dairy	Coal Petro. Sand & Gravel Stone Nat. Gas Cement Zinc & Lead	Print. & pub. Stone, clay, & glass Petro. & coal Food & kin. Apparel & related
K-12 <u>Coffeyville</u> Pop. Cen. S.E. Kansas		Montgomery	Verdigris R.	Sandstone Hills; Prai- rie Grasslands	800 to 1,600	644	38 27	58	33 80	Cash Grain Livestock	Petro. Cement Clay Stone Nat. Gas	Food & kin. Apparel & related Chem. & allied Petro. & coal Stone, clay, & glass Prim. metals Mach., except electrical Trans. equip.
K-13 <u>Pittsburg</u> Pop. Cen. S.E. Kansas		Crawford	Grand (Neo- sho) R.	Claypan Prairies; Prairie Grass- lands	900 to 1,100	605	38 27	58	33 80	Cash Grain Livestock	Coal Petro. Clay Stone Nat. Gas	Food & kin. Apparel & related Stone, clay, & glass Mach., except electrical Trans. equip.

Table IV-1 (Continued)

Subarea Reference City Pop. Type Location	Counties	Geographical Features				Climatological Features			Economic Features		
		Principal Stream(s)	Land Areas & Natural Vegetation	Elev. Above M.S.L.	Area (Square Miles)	Precip. (Mean in.) Annual	Temperature (Mean °F)		Agriculture	Principal Products	
						Apr.-Sep.	Ann- nual	Jan. July		Mining	Manufacturing
T-1 <u>Dalhousie</u> Rural N.W. Texas Panhandle	Oldham Hartley Dallas Sherman Moore Hansford Ochiltree	Cold Water & Palo Duro Crs. Mustang Cr. Canadian R.	High Plains, Cimarron & Canadian Breaks; Plains Grasslands, Prairie Grass- lands	2,600 to 4,600	8,087	20 14	56	34 78	Cash Grain Livestock	Nat. Gas Petro. Sand & Gravel	Chem. & allied Petro. & coal Prim. metals
T-2 <u>Amarillo</u> SMA Gen. Texas Panhandle	Potter Randall	Canadian R. Prairie Dog Down Fk. of Red R.	High Plains, Cimarron & Canadian Breaks; Plains Grasslands	3,000 to 3,800	1,812	20 15	57	35 78	Cash Grain Livestock	Sand & Gravel Nat. Gas	Food & kin. Print. & pub. Petro. & coal Prim. metals
T-3 <u>Pampa</u> SMA Pop. Gen. Gen. Texas Panhandle	Hutchinson Carson Gray	Canadian R. N. Fk. of Red R.	High Plains, Cimarron & Canadian Breaks; Plains Grasslands	2,500 to 3,500	2,720	21 15	57	35 78	Cash Grain Livestock	Petro. Nat. Gas	Chem. & allied Petro. & coal Mach., except electrical
T-4a <u>Canadian</u> Rural N.E. Texas Panhandle	Lipscomb Roberts Stephens	Canadian R. Wolf Cr. Washita R.	Red Plains, Cimarron & Canadian Breaks; Plains Grasslands, Prairie Grass- lands	2,200 to 3,200	2,735	21 14	59	36 81	Livestock Cash Grain	Petro. Nat. Gas	Not of Sig- nificance
T-4b <u>Childress</u> Rural S.E. Texas Panhandle	Wheeler Armstrong Donley Collings- worth Briscoe Hall Childress	North, Salt, & Prairie Dog Town Fks. of Red R.	Red Plains; Plains Grass- lands	1,600 to 3,500	6,108	22 15	61	39 82	Cotton Livestock	Nat. Gas Petro. Stone Sand & Gravel	Chem. & allied
T-5 <u>Hereford</u> Rural S.W. Texas Panhandle	Deaf Smith Farmer Castro Swisher Floyd	Running Water Cr. Prairie Dog Town Fk. of Red R.	High Plains; Plains Grass- lands	2,400 to 4,200	5,123	20 14	58	37 78	Cash Grain Cotton Livestock	Not of Sig- nificance	Not of Sig- nificance
T-6 <u>Plainview</u> Pop. Gen. S. Gen. Texas Panhandle	Hale	White R.	High Plains; Plains Grass- lands	3,200 to 3,600	979	22 16	60	41 78	Cotton Cash Grain	Petro. Clay	Not of Sig- nificance
T-7 <u>Vernon</u> Rural N.W. Gen. S.E. of Texas Panhandle	Motley Cottle Hardeman Wilbarger Foard Dickens King Knox Baylor Stonewall Haskell Throckmorton	Pease R. Wichita R. Brazos R.	Red Plains; Plains Grass- lands	1,000 to 2,400	10,540	24 15	62	43 85	Cotton Livestock Cash Grain	Petro. Nat. Gas Nat. Gas Liq. Sand & Gravel	Stone, clay, & glass Apparel & related
T-8 <u>Wichita Falls</u> SMA N. Texas	Wichita	Wichita R. Red R.	Red Plains; Plains Grass- lands, Prairie Grasslands	900 to 1,200	612	27 16	63	41 84	Livestock Cash Grain	Petro. Nat. Gas Liq. Sand & Gravel Stone Nat. Gas	Food & kin. Apparel & related Print. & pub. Petro. & coal Mach., except electrical
T-9 <u>Graham</u> Rural N. Texas	Archer Clay Jack Young	Little Wich- ita R. W. Fk. of Trinity R. Denton Cr. Brazos R.	Red Prairies; Plains Grass- lands, Prairie Grasslands	800 to 1,400	3,850	28 17	64	44 84	Livestock	Petro. Nat. Gas Liq. Nat. Gas Sand & Gravel	Not of Sig- nificance
T-10 <u>Weatherford</u> Rural N. Gen. Texas	Montague Wise Parker	W. Fk. of Trinity Denton Cr. Brazos R.	Red Prairies, Grand Prairie; Prairie Grass- lands	600 to 1,400	2,750	31 18	63	43 83	Livestock Dairy	Petro. Nat. Gas Nat. Gas Liq. Stone Sand & Gravel	Furn. & fix. Stone, clay, & glass

Table IV-1 (Continued)

Subarea Descriptions											
Subarea Reference City Pop. Type Location		Geographical Features				Climatological Features			Economic Features		
		Principal Stream(s)	Land Areas & Natural Vegetation	Elev. Above MSL	Area (Square Miles)	Precip. (Mean in.) Annual	Temperature (Mean °F)		Agriculture	Principal Products	
							Apr.-Sep.	Annual		Jan.	July
T-11 <u>Sherman</u> Pop. Cen. N. Texas	Cook Grayson	Red R. E. & Elm Pks. of Trinity R.	Coastal Plain, Grand Prairie, Blackland Prairies; Prairie Grasslands	500 to 1,100	1,829	37 22	65	43 84	Livestock Cash Grain Dairy	Petro. Nat. Gas Liq. Nat. Gas Stone Sand & Gravel	Leather Mach., except electrical Food & kin. Apparel & related Lbr. & wood Textile mill Paper & allied Stone, clay, & glass
T-12 <u>Dallas - Ft. Worth</u> SPBA N. Cen. Texas	Denton Collin Tarrant Dallas Johnson Ellis	Denton Cr. E., W., & Elm Pks. of Trinity R.	Coastal Plain, Grand Prairie, Blackland Prairies; Prairie Grasslands	300 to 1,000	5,291	34 19	65	45 84	Cotton Livestock Dairy Cash Grain	Cement Sand & Gravel Stone Clay Lime	Food & kin. Textile mill Apparel & related Lbr. & wood Furn. & fix. Paper & allied Print. & pub. Rubber & plas. Stone, clay, & glass Fab. metals Mach., except electrical Inst. & related Chem. & allied Petro. & coal Prim. metals Elec. mach. Trans. equip.
T-13 <u>Paris</u> Pop. Cen. N.E. Texas	Fannin Lamar Delta	Red R. N. & S. Sulphur R.	Coastal Plain, Black- land Prairies, Alluvial Plains; Prairie Grass- lands	400 to 700	2,088	40 22	64	44 83	Cotton Livestock	Sand & Gravel	Textile mill Lbr. & wood Prim. metals Mach., except electrical Trans. equip. Food & kin. Fab. metals Elec. mach. Apparel & related
T-14 <u>Greenville</u> Pop. Cen. N.E. Texas	Hopkins Bunt Rockwall Kaufman	S. Sul- phur R. Whitesack Cr. Sabine R. E. Pk. of Trinity	Blackland Prairies, Coastal Plain; Prairie Grass- lands, S. Pine- Hardwood Forest	300 to 700	2,666	40 24	65	46 83	Cotton Livestock Dairy	Petro. Nat. Gas Liq. Clay	Apparel & related Fab. metals Food & kin. Elec. mach. Trans. equip. Prim. metals
T-15 <u>Mineola</u> Rural N.E. Texas	Wood Bains Van Zandt	Sabine R.	Blackland Prairies, Coastal Plain; Prai- rie Grass- lands, S. Pine-Hardwood Forest	250 to 600	1,813	40 22	65	46 83	Livestock Cotton	Petro. Nat. Gas Liq. Nat. Gas Lignite Clay	Chem. & allied
T-16 <u>Mt. Pleasant</u> Rural N.E. Texas	Red River Franklin Titus Morris Camp	Red R. Sulphur R. Whitesack Cr.	Coastal Plain, Black- land Prairie; Prairie Grass- lands, S. Pine- Hardwood Forest	250 to 600	2,198	45 21	65	46 83	Livestock Cotton	Petro. Iron Ore Sand & Gravel	Petro. & coal Prim. metals Lbr. & wood
T-17 <u>Texarkana</u> Pop. Cen. N.E. Texas	Bowie Cass	Red R. Sulphur R. Frazier & Black Cy- press Crs.	Coastal Plain; S. Pine-Hardwood Forest, River Bottom Forest	200 to 500	1,886	45 23	65	45 84	Livestock	Petro. Nat. Gas Liq. Iron Ore Nat. Gas	Food & kin. Lbr. & wood Print. & pub. Stone, clay, & glass Trans. equip.

Table IV-1 (Continued)

Subarea Reference City Pop. Type Location	Counties	Geographical Features					Climatological Features			Economic Features		
		Principal Stream(s)	Land Areas & Natural Vegetation	Elev. Above MSL	Area (Square Miles)	Precip. (Mean in.) Annual Apr.-Sep.	Temperature (Mean °F)		Principal Products	Agriculture	Mining	Manufacturing
							Annual	Jan.				
T-18 Marshall Pop. Cen. N.E. Texas	Marion Upshur Gregg Harrison	Sabine R. Little Cy- press Cr.	Coastal Plain; S. Pine-Hard- wood Forest	200 to 600	2,165	45 21	65	47 83	Livestock Cotton Dairy	Petro. Nat. Gas Liq. Nat. Gas Lignite Iron Ore		Apparel & related lbr. & wood Print. & pub. Stone, clay, & glass Fab. metals Mach., except electrical Trans. equip. Chem. & allied Prim. metals
T-19 Henderson Pop. Cen. E. Texas	Rusk Panola	Sabine R.	Coastal Plain; S. Pine-Hard- wood Forest	200 to 750	1,824	44 21	67	50 83	Livestock Cotton	Petro. Nat. Gas Liq. Nat. Gas Clays Lignite		Stone, clay, & glass
O-1 Guymon Rural Okla. Pan- handle	Cimarron Texas Beaver Harper	Cimarron R. N. Canadian R.	High Plains, Red Plains; Plains Grass- lands	1,600 to 5,000	6,715	19 14	57	35 80	Cash Grain Livestock	Nat. Gas Nat. Gas Liq. Petro. Sand & Gravel		Not of Sig- nificance
O-2a Woodward Rural N.W. Okla.	Ellis Blaine Dewey Woodward	N. Canadian R. Wolf Cr. Canadian R.	Red Plains, Red Prairies; to Prairie Grass- lands	1,200 to 2,500	4,342	24 17	60	37 83	Cash Grain Livestock Dairy	Petro. Nat. Gas Sand & Gravel Bentonite Gypsum		Stone, clay, & glass
O-2b Clinton Rural W. Cen. Okla.	Roger Mills Custer Beckham Washita Harmon Greer Kiowa	Washita R. W. Fk. Red R.	Red Plains, Wichita Mts.; Prairie Grass- lands	1,300 to 2,600	6,231	24 16	61	39 83	Livestock Cotton	Petro. Nat. Gas Nat. Gas Liq. Salt Clays Sand & Gravel		Food & kin.
O-3 Alva Rural N.W. Okla.	Woods Alfalfa Grant Major	Salt Fk. of Ark. R. Cimarron R.	Red Plains, Red Prairies; Prairie Grass- lands	1,000 to 2,000	4,028	25 18	60	37 84	Cash Grain Livestock	Petro. Nat. Gas Nat. Gas Liq. Salt Sand & Gravel		Not of Sig- nificance
O-4 Enid Pop. Cen. N. Cen. Okla.	Garfield	Turkey Cr. Skeleton Cr.	Red Prairies; Prairie Grass- lands	1,000 to 1,400	1,054	28 19	61	38 84	Cash Grain Livestock	Petro. Nat. Gas Liq. Nat. Gas		Food & kin. Print. & pub. Petro. & coal Prim. metals Mach., except electrical
O-5 Ponca City Pop. Cen. N. Cen. Okla.	Kay	Ark. R. Salt Fk. Chikaskia R.	Red Prairies, Bluestem Hills; Prairie Grass- lands	800 to 1,200	944	31 22	60	36 83	Cash Grain Livestock	Petro. Nat. Gas Liq. Nat. Gas		Petro. & coal Prim. metals Mach., except electrical Apparel & related
O-6 Tulsa INSA N.E. Okla.	Osage Creek Washington Tulsa	Ark. R. Caney R. Polecat Cr.	Bluestem Hills, Cross Timbers, Claypan Prai- ries; Prairie Grasslands	600 to 1,400	4,262	37 24	61	37 82	Livestock Dairy	Petro. Nat. Gas Liq. Nat. Gas Clay Sand & Gravel		Apparel & related Petro. & coal Prim. metals Mach., except electrical Food & kin. Paper & allied Print. & pub. Chem. & allied Stone, clay, & glass Fab. metals Elec. mach. Trans. equip.
O-7 Stillwater Pop. Cen. N. Cen. Okla.	Noble Pawnee Kirkfisher Logan Payne Lincoln	Ark. R. Cimarron R.	Red Prairies, Cross Timbers; Prairie Grass- lands	700 to 1,400	4,641	31 21	61	38 83	Livestock Cash Grain Dairy	Petro. Nat. Gas Liq. Nat. Gas Sand & Gravel		Furn. & fix. Petro. & coal

Table IV-1 (Continued)

Subarea Reference City Pop. Type Location	Counties	Geographical Features				Climatological Features			Economic Features		
		Principal Stream(s)	Land Areas & Natural Vegetation	Elev. Above MEL	Area (Square Miles)	Precip. (Mean in.) Annual Apr.-Sep.	Temperature (Mean °F)		Principal Products	Agriculture	Manufacturing
							Annual	Jan.			
							Apr.-Sep.	Jan.			
0-8 <u>Oklahoma City</u> DMA Cen. Okla.	Canadian Oklahoma Cleveland	N. Canadian R. Canadian R.	Red Prairies. Cross Timbers; Prairie Grass- lands	900 to 1,600	2,141	32 21		61 82	Livestock Cash Grain Dairy	Petro. Nat. Gas Liq. Nat. Gas Sand & Gravel	Food & kin. Apparel & related Furn. & fix. Paper & allied Print. & pub. Stone, clay, & glass Fab. metals Mach., except electrical Elec. mach. Trans. equip.
0-9 <u>Duncan</u> Pop. Cen. S. Cen. Okla.	McCain Caddo Grady Garvin Stephens Murray	Canadian R. Washita R.	Red Plains. Cross Timbers. Red Prairies. Grand Prairie; Prairie Grass- lands	700 to 1,800	5,061	34 22		63 83	Livestock Cash Grain Dairy Cotton	Petro. Nat. Gas Liq. Nat. Gas Sand & Gravel Gypsum	Petro. & coal Food & kin. Mach. electrical
0-10 <u>Lawton</u> DMA S.W. Okla.	Comanche	Cache Cr. W. Cache Cr. Beaver Cr.	Red Plains Wichita Mts., Red Prairie; Prairie Grass- lands	1,000 to 2,500	1,088	30 19		63 84	Livestock Cash Grain Dairy	Petro. Nat. Gas Sand & Gravel	Food & kin. Trans. equip.
0-11 <u>Altus</u> Pop. Cen. S.W. Okla.	Jackson	Salt Pk. Prairie Dog Town Pk. & N. Pk. of Red R.	Red Plains; Prairie Grass- lands	1,200 to 2,200	780	24 16		63 85	Cotton Livestock	Petro. Nat. Gas Sand & Gravel	Not of Sign- ificance
0-12 <u>Frederick</u> Rural S.W. Okla.	Tillman Cotton Jefferson Love	Red R. Beaver Cr.	Red Plains. Red Prairies. Cross Timbers. Grand Prairie. Coastal Plains; Prairie Grass- lands	600 to 1,400	2,733	31 19		64 85	Livestock Cash Grain Cotton	Petro. Nat. Gas Sand & Gravel	Leather
0-13 <u>Ardmore</u> Pop. Cen. S. Cen. Okla.	Carter	Washita R.	Cross Timbers. Grand Prairie; Prairie Grass- lands	700 to 1,400	829	37 22		64 84	Livestock	Petro. Nat. Gas Liq. Nat. Gas	Food & kin. Petro. & coal
0-14 <u>Shawnee</u> Pop. Cen. E. Cen. Okla.	Coal Pontotoc Pottawatomie Seminole Oklfuskee McIntosh Hughes	N. Canadian R. Canadian R. Buddy & Clear Boggy Crs.	Cross Timbers. Claypan Prai- ries. Grand Prairie; Prai- rie Grasslands	500 to 1,300	4,834	40 24		62 83	Livestock Dairy	Petro. Nat. Gas Liq. Nat. Gas Coal Cement Sand & Gravel Clays	Apparel & related Stone, clay, & glass Food & kin. Elec. mach. Trans. equip. Lbr. & wood
0-15 <u>Muskogee</u> Pop. Cen. E. Cen. Okla.	Oklmulgee Muskogee	Ark. R. Deep Pk. R.	Cross Timbers. Claypan Prai- ries; Prairie Grasslands	400 to 1,100	1,520	41 24		62 83	Livestock Cotton Dairy	Petro. Nat. Gas Coal Sand & Gravel	Petro. & coal Prim. metals Stone, clay, & glass Food & kin. Paper & allied Rubber & plas. Fab. metals
0-16 <u>Claremore</u> Rural N.E. Okla.	Nowata Craig Rogers Mayes Wagoner	Verdigris R. Grand (Neosho) R.	Claypan Prai- ries. Bluestem Hills; Prairie Grasslands	500 to 1,000	3,314	40 25		60 82	Livestock Dairy Cash Grain	Petro. Nat. Gas Coal Sand & Gravel	Textile mill Leather Paper & allied Chem. & allied
0-17 <u>Miami</u> Rural N.E. Okla.	Ottawa Delaware Cherokee Adair	Grand (Neosho) R. Illinois R.	Claypan Prai- ries, Ozark; Upland Hard- woods Forest	500 to 1,200	2,532	43 28		60 81	Livestock Dairy Cash Grain Poultry	Petro. Zinc Lead Sand & Gravel	Petro. & coal Food & kin.
0-18 <u>McAlester</u> Pop. Cen. E. Cen. Okla.	Pittsburg	Canadian R.	Ouschita Mts., Claypan Prai- ries; Prairie Grasslands	500 to 1,500	1,359	42 25		62 83	Livestock	Coal Nat. Gas Clay	Food & kin. Apparel & related

Table IV-1 (Continued)

Subarea Descriptions											
Subarea Reference City Pop. Type Location	Counties	Geographical Features			Climatological Features			Economic Features			
		Principal Stream(s)	Land Areas & Natural Vegetation	Elev. Above MSL	Area (Square Miles)	Precip. (Mean in.) Annual	Temperature (Mean °F)		Agriculture	Principal Products	Manufacturing
						Apr.-Sep.	An- nual	Jan. July		Mining	
0-19a <u>Poteau</u> Rural E. Cen. Okla.	Sequoyah Baskell Latimer LeFlore	Ark. R. Poteau R. Fouche Maline R.	Ozarks. Ouachita Mts., Ark. Valley; Up- land Hard- wood Forest, River Bottom Forest	400 to 2,700	3,629	44 24	62	40 82	Livestock	Coal Nat. Gas Sand & Gravel	Food & kin.
0-19b <u>Hugo</u> Rural S.E. Okla.	Pushmataha Choctaw McCurain	Red R. Kiamichi R. Little R. Mountain Pk. R.	Ouachita Mts., Coast- al Plains, Grand Prai- rie, Alluvial Plains; S. Pine-Hardwood Forest, Prai- rie Grasslands	300 to 1,900	4,061	47 24	63	44 82	Livestock	Sand & Gravel Petro.	Apparel & related lbr. & wood
0-20 <u>Durant</u> Rural S. Cen. Okla.	Johnston Atoka Marshall Bryan	Red R. Washita R. Clear & Muddy Boggy Crs. Blue R.	Grand Prai- rie, Coastal Plains, Ar- buckle Mts., Ouachita Mts., Prairie Grass- lands	400 to 1,200	2,879	39 22	64	43 83	Livestock	Petro. Nat. Gas Liq. Nat. Gas Sand & Gravel	Apparel & related
M-1 <u>Joplin</u> Pop. Cen. S.W. Missouri	Jasper Newton	Spring R.	Ozark, Clay- pan Prairie; Upland Hard- wood Forest, Prairie Grass- lands	1,000 to 1,400	1,257	44 28	58	35 78	Dairy Livestock Cash Grain	Sand & Gravel Stone	Food & kin. Apparel & related lbr. & wood Print. & pub. Chem. & allied Petro. & coal Leather Stone, clay, & glass Prim. metals Fab. metals Elec. mach. Trans. equip.
M-2 <u>Aurora</u> Rural S.W. Missouri	Barton Dade Lawrence Stone Berry McDonald	Spring R. White R.	Ozark, Clay- pan Prairie; Upland Hard- wood Forest, Prairie Grass- lands	1,000 to 1,500	3,527	45 28	57	36 78	Dairy Livestock Cash Grain	Stone Coal Sand & Gravel	Mach., except electrical Food & kin. Apparel & related Print. & pub. Leather Fab. metals
A-1 <u>Fayetteville</u> Pop. Cen. N.W. Ark.	Benton Washington	Illinois R. White R. Spavinaw Cr.	Ozark, Ouachita Mts.; Upland Hard- wood Forest	1,000 to 1,500	1,831	47 27	60	38 78	Poultry Dairy Livestock	Stone Sand & Gravel Nat. Gas	Food & kin. Textile mill Apparel & related lbr. & wood Prim. metals
A-2 <u>Harrison</u> Rural N.W. Ark.	Carroll Boone Madison Newton Searcy	White R.	Ozark, Ouachita Mts.; Upland Hard- wood Forest	1,000 to 2,500	3,604	43 24	59	26 76	Livestock Dairy Poultry	Sand & Gravel Clay Manganese	Food & kin. Apparel & related Furn. & fix. lbr. & wood
A-3 <u>Van Buren</u> Rural N.W. Cen. Ark.	Crawford Franklin Johnson Pope Logan Scott Yell Perry Conway Van Buren Cleburne Faulkner	Ark. R. Petit Jean Cr. Fourche La Fave R.	Ark. Valley, Ouachita Mts.; Upland Hard- wood Forest, S. Pine-Hard- wood Forest, River Bottom Forest	500 to 2,800	8,532	52 26	62	42 81	Livestock Poultry Dairy Cotton Cash Grain	Sand & Gravel Stone Nat. Gas Coal Clay	Food & kin. Leather Rubber & plas. Furn. & fix. Textile mill Apparel & related Trans. equip.
A-4 <u>Ft. Smith</u> SMSA W. Ark.	Sebastian	Ark. R.	Ouachita Mts., Ark. Valley, Claypan Prai- ries; Upland Hardwood Forest, River Bottom Forest	500 to 1,000	531	40 23	62	40 82	Dairy Livestock	Coal Nat. Gas Stone Clay	Food & kin. Furn. & fix. Paper & allied Print. & pub. Stone, clay, & glass Prim. metals Fab. metals Elec. mach.

Table IV-1 (Continued)

Subarea Reference City Pop. Type Location	Counties	Geographical Features				Climatological Features			Economic Features		
		Principal Stream(s)	Land Areas & Natural Vegetation	Elev. Above MSL	Area (Square Miles)	Precip. (Mean in.) Annual Apr.-Sep.	Temperature (Mean °F)		Principal Products	Agriculture	Manufacturing
							Annual	Jan.			
A-5 <u>Benton</u> Rural Cen. & W. Cen. Ark.	Polk Montgomery Hot Springs Clark Saline	Ouachita R. Caddo R. Little Mo. R.	Ouachita Mts., Coastal Plains; S. Pine-Hard- wood Forest	100 to 1,500	4,868	52 24	63	43 82	Livestock Poultry Dairy	Bauxite Clay Sand & Gravel Lime Talc Stone Manganese Slate Barite Gem Stones	Apparel & related Textile mill Stone, clay, & glass Prim. metals Lbr. & wood Chem. & allied
A-6 <u>Hot Springs</u> Pop. Cen. Cen. Ark.	Garland	Ouachita R.	Ouachita Mts.; S. Pine-Hard- wood Forest	500 to 1,500	738	56 28	63	44 82	Livestock	Oilstones Grinding pebbles Sand & Gravel Gem Stones Whetstones	Lbr. & wood
A-7 <u>Little Rock</u> SWSA Cen. Ark.	Fulaski Jefferson	Ark. R.	Ouachita Mts., Alluvial Plains, Coastal Plains; S. Pine-Hardwood Forest	100 to 750	1,684	48 21	62	42 81	Cotton	Stone Sand & Gravel Bauxite Clays	Food & kin. Textile mill Apparel & related Lbr. & wood Furn. & fix. Paper & allied Print. & pub. Stone, clay, & glass Elec. mach. Inst. & related Fab. metals Trans. equip. Prim. metals
A-8 <u>Stuttgart</u> Pop. Cen. E. Cen. Ark.	White Lonoke Arkansas Monroe Prairie	Bayou Mato L. Red R.	Loess Hills & Terraces, Al- luvial Plains, Ouachita Mts.; River Bottom Forest, Upland Hardwood Forest	100 to 750	4,109	52 23	63	43 82	Cotton Cash Grain Livestock	Stone Clay	Food & kin. Leather Mach., except electrical Apparel & related
A-9 <u>Texarkana</u> Pop. Cen. S.W. Ark.	Sevier Howard Pike Little R. Hempstead Miller Lafayette	Red R. Little R. Cossatot R. Rolling Yk. Saline R. Little Mo. R. Bodcan Bayou	Coastal Plains, Ouachita Mts., Alluvial Plains; S. Pine-Hard- wood Forest, River Bottom Forest	100 to 750	4,220	49 24	64	46 83	Livestock Cotton Poultry	Cement Sand & Gravel Gypsum Gem Stones Stone Petro. Nat. Gas Sulphur Nat. Gas Liq.	Lbr. & wood Stone, clay, & glass Apparel & related Petro. Nat. Gas Sulphur Nat. Gas Liq.
A-10 <u>Magnolia</u> Rural S.W. Ark.	Nevada Columbia	Bayou Dor- cheat	Coastal Plains; S. Pine-Hard- wood Forest	100 to 500	1,384	49 22	65	47 82	Livestock	Petro. Sand & Gravel Nat. Gas Nat. Gas Liq.	Lbr. & wood Apparel & related
A-11 <u>El Dorado</u> Pop. Cen. S. Cen. Ark.	Ouachita Union	Ouachita R. Little Mo. R.	Coastal Plain; S. Pine-Hard- wood Forest, River Bottom Forest	100 to 500	1,790	53 23	65	46 82	Livestock	Petro. Sand & Gravel Nat. Gas Clays Bromine Nat. Gas Liq.	Lbr. & wood Furn. & fix. Paper & allied Petro. & coal Trans. equip. Food & kin. Apparel & related Fab. metals
A-12 <u>Marion</u> Rural S. Cen. Ark.	Grant Dallas Cleveland Claboun Bradley	Moro Cr. Ouachita R. Saline R.	Coastal Plains; S. Pine-Hardwood Forest, River Bottom Forest	100 to 500	3,184	54 23	64	46 82	Cotton Livestock Poultry	Sand & Gravel Petro.	Lbr. & wood
A-13 <u>Crossett</u> Rural S.E. Ark.	Lincoln Desha Drew Ashley Chicot	Bayou Bar- tholomew Ark. R. Saline R. Miss. R.	Alluvial Plains, Loess Hills & Ter- races, Coast- al Plains; S. Pine-Hard- wood Forest, River Bottom Forest	100 to 500	3,774	53 23	64	45 82	Cotton Livestock	Sand & Gravel	Apparel & related Textile mill Trans. equip. Lbr. & wood Paper & allied Chem. & allied

Table IV-1 (Continued)

Subarea Reference City Pop. Type Location	Counties	Geographical Features				Climatological Features			Economic Features		
		Principal Stream(s)	Land Areas & Natural Vegetation	Elev. Above MSL	Area (Square Miles)	Precip. (Mean in.) Annual	Temperature (Mean °F)		Agriculture	Principal Products	
						Apr.-Sep.	Annual	Jan. July		Mining	Manufacturing
L-1 <u>Shreveport</u> SMA N.W. Louisiana	Caddo Bossier Webster	Red R. Bayou Dor- cheat Bayou Bodcau	Coastal Plains, Alluvial Plains; S. Pine-Hard- wood Forest, River Bottom Forest	100 to 250	2,571	45 21	66	48 83	Livestock Cotton	Petro. Nat. Gas Nat. Gas Liq. Sand & Gravel	Food & kin. Lbr. & wood Print. & pub. Stone, clay, & glass Fab. metals Mach., except electrical Chem. & allied Petro. & coal Leather Prim. metals Paper & allied
L-2 <u>Easton</u> Rural N. Cen. Louisiana	Clairborne Union Lincoln Bienville Red R. DeSoto Jackson Winn Caldwell Grant La Salle	Red R. Bayou D'Arbonne Little R. Black Lake Bayou Saline Bayou	Coastal Plains, Al- luvial Plains; S. Pine- Hardwood Forest	100 to 300	7,670	54 23	66	48 82	Livestock Cotton	Petro. Nat. Gas Nat. Gas Liq. Clay Sand & Gravel Shell	Lbr. & wood Fab. metals Paper & allied
L-3 <u>Monroe</u> SMA N.E. Louisiana	Ouachita Morehouse	Ouachita R. Bertholo- meu Bayou Rouff R.	Coastal Plains, Alluvial Plains; River Bottom Forest	50 to 300	1,446	53 25	66	48 82	Cotton Livestock	Nat. Gas Petro. Sand & Gravel Clay	Food & kin. Apparel & related Lbr. & wood Paper & allied Print. & pub. Chem. & allied
L-4 <u>Tallulah</u> Pop. Cen. N. Cen. E. Louisiana	W. Carroll E. Carroll Richland Madison Franklin Tensas Catahoula Concordia Avoyelles	Tensas R. Macon Bayou Rouff R.	Loess Hills & Terraces, Alluvial Plains; River Bottom Forest	50 to 150	5,564	52 22	65	49 81	Cotton Livestock	Nat. Gas Petro. Sand & Gravel Nat. Gas Liq.	Lbr. & wood Food & kin. Mach., except electrical
L-5 <u>Hatchitoches</u> Pop. Cen. Louisiana	Hatchi- toches	Red R.	Coastal Plains; Al- luvial Plains; River Bottom Forest, S. Pine-Hardwood Forest	100 to 350	1,297	52 24	66	50 82	Cotton Livestock	Petro. Clay Nat. Gas	Food & kin.
L-6 <u>Alexandria</u> Pop. Cen. Cen. Louisiana	Rapides	Red R.	Coastal Plains, Al- luvial Plains; S. Pine-Hard- wood Forest, River Bottom Forest	50 to 250	1,329	57 27	67	51 81	Cotton Livestock	Sand & Gravel Petro. Clay Nat. Gas	Food & kin. Lbr. & wood Leather

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V. ECONOMICS AND POPULATION

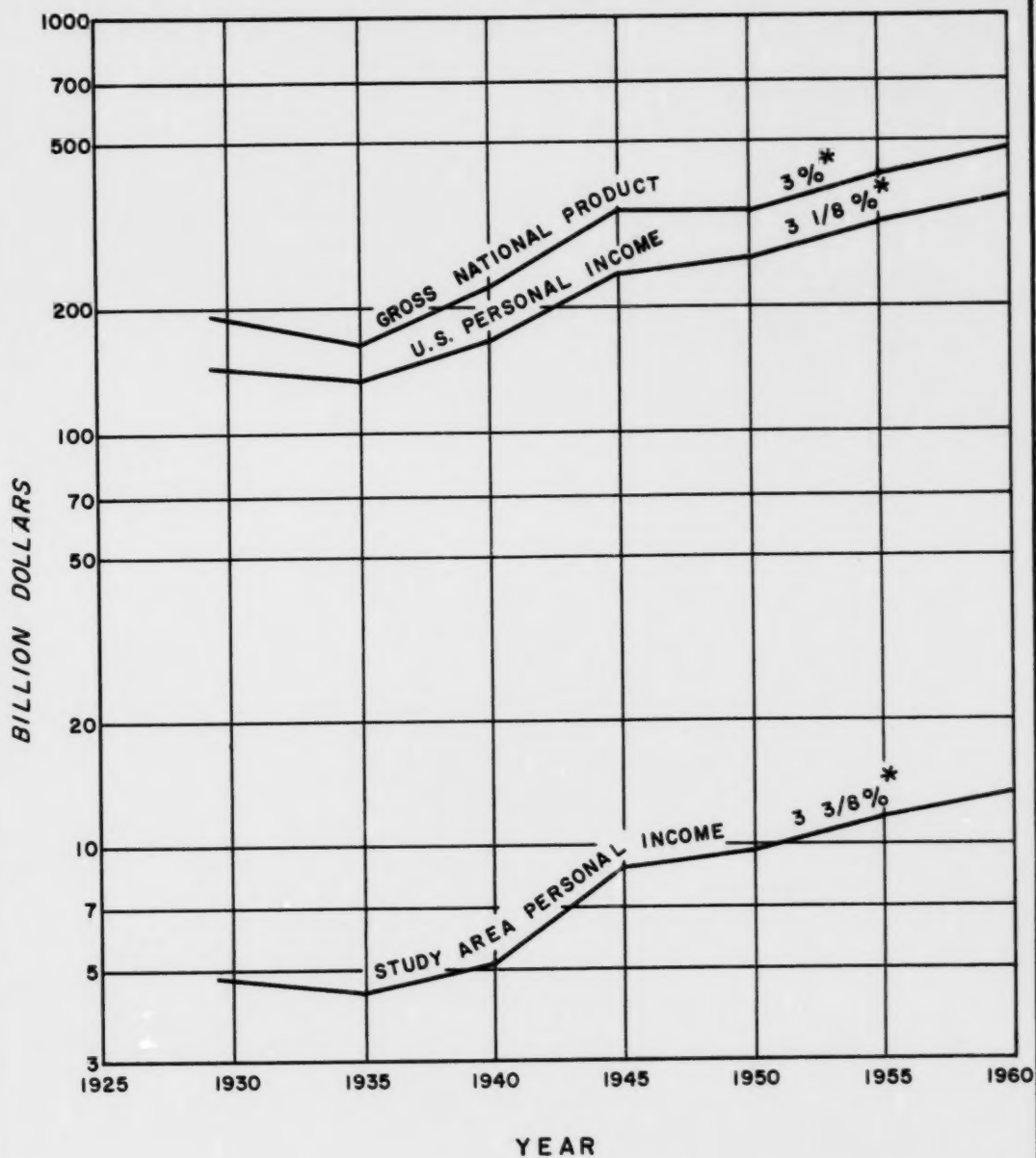
Economics of the Study Area

National growth in production of goods and services is reflected differently in all portions of the United States, because of the tendency toward regional production specialization. The larger the region, however, the more nearly it parallels overall national growth. An examination of historic growth trends in the Nation and the Ark-Red study area, therefore, provides a good indication of relative growth of the study area.

Personal Income

The most meaningful and widely accepted single measure of national output is gross national product (GNP). Since directly comparable figures are not available on a regional basis, national personal income is used as a substitute in this comparative analysis. Historic trends of gross national product and personal income for the United States appearing in Figure V-1 demonstrate the parallelism of these two criteria.

For this study, personal income for selected States is used as the method of comparing growth in the study area to that of the United States. Since the majority of population and industry in Colorado, New Mexico, Missouri, and Louisiana is located outside the study area, these States are not included in estimates of study area personal income. In the remaining States - Kansas,



* AVERAGE ANNUAL GROWTH RATE

NOTE: ADJUSTED TO 1957 CONSTANT DOLLAR

ARKANSAS-RED RIVER BASINS
WATER QUALITY CONSERVATION PROJECT-
BENEFITS EVALUATION
GNP AND PERSONAL
INCOME TRENDS

DEPARTMENT OF HEALTH, EDUCATION, & WELFARE
PUBLIC HEALTH SERVICE
REGION VII DALLAS, TEXAS

FIGURE V-1

Oklahoma, Texas, and Arkansas - total State personal income is weighted according to the proportion of population within the study area. Tabulations of personal income for these States and their study area component appear in Table V-1.

Personal income trends in the study area and the United States for the period 1929 through 1959 appear in Figure V-1. Analysis of these data indicates personal income adjusted to 1957 constant dollars grew 170 percent in the study area during this period compared to 150 percent growth for the entire United States. (See Figure V-2.) Per capita personal income for the same period of time, however, grew 130 percent in the study area and 76 percent in the United States. This comparison is also depicted in Figure V-2. These trends reflect changes in the study area from an agrarian to an industrial economy.

Employment

An indicator of the present economy is provided by an examination of employment by major industries in the Nation and the Ark-Red study area. Employment data for 1960 in the study area are summarized by States in Table V-2. The total basic category includes all commodity-producing industries (agriculture, forestry, fishing, mining, construction, and manufacturing). The total service employment includes all noncommodity-producing industries (wholesale and retail trade, government, and others). In 1960, 9.1 percent of the area Labor

Table V-1

Personal Income by States ^{1 2 /}
(Million Dollars)

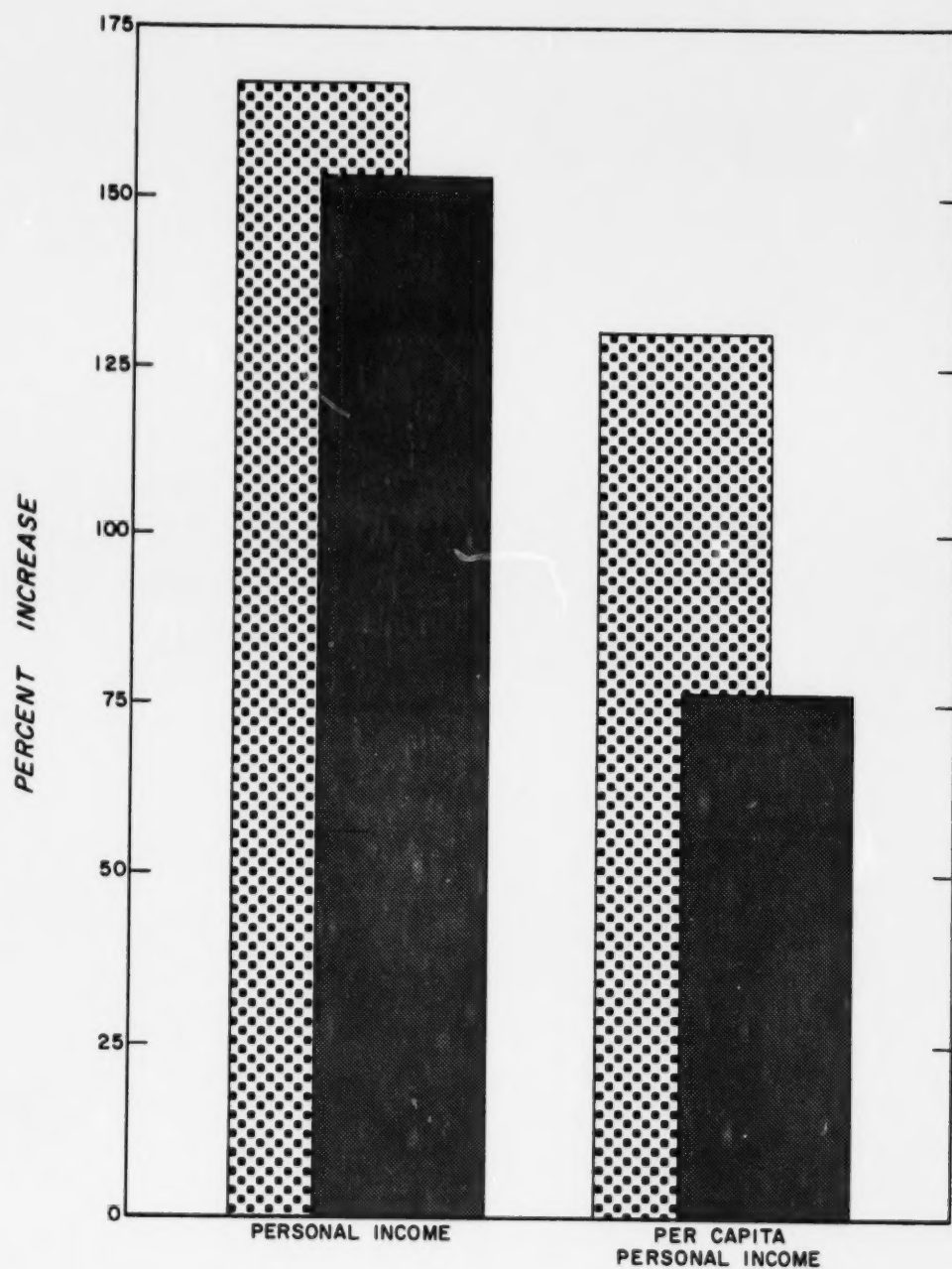
	<u>1929</u>	<u>1935</u>	<u>1940</u>	<u>1945</u>	<u>1950</u>	<u>1955</u>	<u>1959</u>
<u>Kansas</u>							
a	999	668	762	1,992	2,643	3,458	4,238
b	49.8	49.7	49.7	49.8	49.9	49.5	49.0
c	496	332	379	992	1,319	1,712	2,078
d	835	754	798	1,463	1,542	1,811	1,998
<u>Oklahoma</u>							
a	1,077	699	867	1,958	2,514	3,341	4,138
b	100.0	100.0	100.0	100.0	100.0	100.0	100.0
c	1,077	699	867	1,958	2,514	3,341	4,138
d	1,815	1,587	1,826	2,889	2,940	3,535	3,982
<u>Texas</u>							
a	2,752	1,950	2,776	7,169	10,375	14,380	18,041
b	33.6	33.4	32.6	31.0	31.4	31.2	31.1
c	925	651	905	2,223	3,258	4,487	5,619
d	1,560	1,478	1,906	3,278	3,808	4,747	5,398
<u>Arkansas</u>							
a	564	380	501	1,270	1,539	1,933	2,370
b	71	70.6	70.3	70.2	70.2	71.0	72.6
c	400	268	352	892	1,082	1,372	1,729
d	674	608	741	1,316	1,265	1,451	1,656
S.A. Total	2,898	1,950	2,503	6,065	8,173	10,912	13,564
1957							
Dollars	4,884	4,427	5,271	8,946	9,555	11,544	13,034
U.S. Total	83,661	60,104	78,522	164,549	225,473	306,598	380,664
1957							
Dollars	144,400	136,436	165,300	242,700	263,700	321,000	366,400

a. Total State personal income

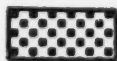
b. Percent of State population in study area

c. Weighted average - total study area personal income

d. Total study area personal income converted to 1957 constant dollars



LEGEND



STUDY AREA



U. S.

ARKANSAS-RED RIVER BASINS
WATER QUALITY CONSERVATION PROJECT-
BENEFITS EVALUATION

PERSONAL INCOME GROWTH

1929-1959 (1957 CONSTANT DOLLAR)

DEPARTMENT OF HEALTH, EDUCATION, & WELFARE
PUBLIC HEALTH SERVICE

REGION VII

DALLAS, TEXAS

FIGURE V-2

Table V-2

Employment by Industries for the Study Area 1960 3/

	Agri- culture	Forestry & Fish.	Mining	Con- struc- tion	Manu- fac- turing	Total Basic	Total Service	Employed	Un- employed	Total Labor Force	Percent Un- employed
Tex.	76,683	207	28,497	82,695	218,893	406,975	708,470	1,115,445	40,739	1,156,184	3.5
Colo.	11,912	103	2,311	8,424	20,790	43,540	85,186	128,726	6,345	135,071	4.7
New Mex.	4,079	27	195	2,166	1,534	8,001	18,485	26,486	1,761	28,247	6.2
Oklahoma	73,539	319	35,129	56,693	104,134	269,814	516,134	785,948	34,423	820,371	4.2
Ark.	51,607	1,383	4,500	28,371	88,924	174,785	247,067	421,852	24,793	446,645	5.6
La.	29,721	1,294	7,614	22,933	42,114	103,676	184,626	288,302	17,147	305,449	5.6
Kans.	49,614	55	11,445	22,728	75,480	159,322	232,780	392,102	15,378	407,480	3.8
No.	10,075	31	250	3,972	14,923	29,251	35,456	64,707	3,103	67,810	4.6
Study Area Total	307,230	3,419	89,941	227,982	566,792	1,195,364	2,028,204	3,223,568	143,689	3,367,257	4.3

force was employed in agriculture compared to 9.5 percent for the United States. The unemployed represented 4.3 percent of the study area's labor force in 1960 compared to 5.0 percent of the national labor force.

Extractive Industries

Another measure of the economy of the study area is the value of products sold and the relative importance to the Nation of various extractive industries.

Minerals

The study area has averaged producing about 15 percent of the value of minerals extracted in the United States since 1953. The value of minerals produced in each State of the study area and in the United States appears in Table V-3.

In terms of value added, petroleum and natural gas are the most significant minerals extracted in the study area. The importance of these industries in the basins is quite apparent when value added by petroleum and natural gas extraction is compared to total value of all minerals produced in the study area. In 1960, crude petroleum, natural gas, and natural gas liquids extraction accounted for about \$2.22 billion, or 90 percent of the value added by all mineral production in the basins.^{2/} Petroleum and natural gas extraction in the study area contributed 22 percent of the value added by these industries nationally.

Table V-3

Value of Minerals Produced in the Study Area and the U.S. 1953-1960 $\frac{L}{U}$
(1,000-1957 dollars)

	1953	1954	1955	1956	1957	1958	1959	1960
Texas	1,081,701	1,111,629	1,045,166	1,045,039	997,554	1,050,332	1,058,048	1,012,885
Colorado	64,578	77,967	86,346	87,590	82,187	67,614	78,801	92,071
New Mexico	2,890	761	964	1,291	1,106	1,148	2,583	2,210
Oklahoma	726,737	704,887	772,314	797,925	809,004	798,493	795,980	802,334
Arkansas	124,701	130,616	130,763	72,310	77,807	77,491	71,715	79,451
Louisiana	229,286	228,551	200,306	158,922	255,669	268,460	249,752	271,311
Kansas	301,419	340,087	365,368	370,746	321,107	327,480	359,074	360,619
Missouri	4,637	3,458	2,923	3,404	2,846	2,850	3,011	3,038
Total	2,535,949	2,597,956	2,602,150	2,577,227	2,551,271	2,593,868	2,618,964	2,623,919
U.S. Total	15,431,585	15,250,035	17,151,691	18,300,973	18,113,000	17,187,467	17,928,916	18,425,182
Study Area % of U.S.	16.4	17.0	15.2	14.1	14.1	15.1	14.6	14.3

Chief areas of petroleum and natural gas extraction in the basins are: southern Kansas; panhandle, north, and north-central Oklahoma; panhandle, north-central, and east Texas; southern Arkansas; and northern Louisiana. ^{5 6} /

Forestry

Most of the eastern portion of the study area is covered by forests. Studies by the Forest Service indicate that 62 percent of the land area of Arkansas and 56 percent of Louisiana are covered by forests. ^{7 3} / Forests are also prevalent in eastern Oklahoma and Texas portions of the study area.

There is a trend toward more growing stock of softwoods with a decrease in hardwoods. This fact is especially true in Arkansas and Louisiana where hardwoods, which usually grow in the alluvial flood plains, are being cleared for agricultural crop production. The increase of softwoods is occurring in the uplands where extensive restocking of pines to replace hardwoods is being promoted.

The hardwood is used primarily for flooring, furniture, veneers, poles, pilings, and cooperage.

Most of the softwood is used by the pulp and paper industry, the area's fastest growing segment of the forest industry.

Pulpwood production in the study area has nearly doubled from 1946 to 1959 with Arkansas and Louisiana being responsible for most of the pulpwood production in the study area as shown in Table V-4.

Table V-4 ^{9/}

Pulpwood Production Ark-Red Study Area 1946-1959
(1,000 Cords)

<u>State</u>	<u>1946</u>	<u>1951</u>	<u>1955</u>	<u>1959</u>
Arkansas	572	602	871	1,177
Louisiana	594	679	1,036	1,100
Oklahoma	13	45	38	38
Texas	<u>111</u>	<u>228</u>	<u>207</u>	<u>134</u>
TOTAL	1,290	1,554	2,152	2,499

Agriculture

The agricultural economy of the study area is influenced by many factors outside the Ark-Red basins. In addition to satisfying local demands, agricultural production in the area is directed toward national and international markets. For example, U. S. exports of wheat, cotton, rice, and sorghums, four of the study area's major crops, amount to 29, 24, 29, and 16 percent, respectively, of the United States production in 1958. ^{10/}

An analysis of ranking agricultural counties in the United States indicates various portions of the study area excel in a number of farm products. For instance, Washington and Benton

Counties ranked third and fourth, respectively, in U. S. broiler production. 11/

In wheat acreage, six of the top ten counties in the United States are located in the study area, as do three of the first ten counties in acres of grain sorghums. Top ranking counties in acres of rice, soybeans, peanuts, strawberries, and sweet potatoes are also in the Ark-Red area.

The number of farms and acres of cropland harvested have paralleled the declining trend of the United States as shown in Table V-5. However, this decrease was accompanied by an increase in total value of farm products sold. The study area is providing an increasing portion of the livestock sold in the United States as shown in Table V-5. These trends indicate a movement in the study area toward higher specialized crop production and more extensive livestock program.

Table V-5 shows the phenomenal increase of irrigation in the study area in the past 15 years. Irrigated acreage in the study area was 5.2 percent of the United States total in 1944 and 13.4 percent in 1959. Most of this increase is the result of extensive ground water irrigation development in the High Plains portion of the study area. A more detailed evaluation of irrigation development and potential appears in Appendix - Exhibit D of this report.

Table V-5

Summary of Agricultural Statistics ^{12/}

	Number of Farms (100)			
	1944	1949	1954	1959
Texas	1,306	1,136	957	728
Colorado	135	131	118	96
New Mexico	68	55	48	39
Oklahoma	1,648	1,422	1,190	947
Arkansas	1,260	1,174	931	626
Louisiana	676	622	557	338
Kansas	677	635	525	511
Missouri	213	207	180	167
Total	5,983	5,382	4,566	3,430
U.S. Total	59,670	56,480	50,870	37,040
% of U.S.	10.0	9.5	9.0	9.3

	Acres of Cropland Harvested (1,000)			
	1944	1949	1954	1959
Texas	12,318	11,737	10,323	8,727
Colorado	2,002	2,599	1,693	2,099
New Mexico	886	864	453	440
Oklahoma	14,088	11,896	10,249	8,973
Arkansas	3,344	3,174	2,632	2,193
Louisiana	1,576	1,432	1,298	1,088
Kansas	12,770	12,020	11,889	11,323
Missouri	958	822	776	710
Total	47,942	44,544	39,313	33,703
U.S. Total	403,000	409,000	399,000	381,000
% of U.S.	11.9	10.9	9.9	8.9

	Acres of Irrigation (1,000)			
	1944	1949	1954	1959
Texas	261	937	1,798	2,324
Colorado	464	497	347	308
New Mexico	70	79	96	163
Oklahoma	2	34	108	198
Arkansas	165	240	465	414
Louisiana	3	7	57	20
Kansas	95	133	290	630
Missouri	---	---	3	1
Total	1,060	1,927	3,164	4,458
U.S. Total	20,539	25,905	29,552	33,311
% of U.S.	5.2	7.4	10.6	13.4

Table V-5 (Continued)

	Value of Crops*			
	1944	1949	1954	1959
Texas	259,229	395,282	316,105	370,607
Colorado	31,744	53,848	19,816	56,061
New Mexico	7,624	14,076	5,449	11,475
Oklahoma	225,647	255,801	201,974	255,125
Arkansas	77,575	51,909	128,843	163,332
Louisiana	63,422	80,789	83,292	92,285
Kansas	107,712	198,485	216,357	282,182
Missouri	6,530	9,621	13,791	15,242
Total	679,483	1,059,819	985,627	1,248,309
U.S. Total	8,576,732	9,981,727	11,481,184	13,346,836
% of U.S.	10.3	10.6	8.6	9.6

	Value of Livestock Sold*			
	1944	1949	1954	1959
Texas	174,711	182,071	168,793	299,955
Colorado	44,718	57,861	51,772	87,722
New Mexico	16,246	24,863	22,269	35,169
Oklahoma	409,928	493,081	388,232	314,838
Arkansas	58,461	66,534	90,523	153,970
Louisiana	13,792	21,268	28,687	53,609
Kansas	183,705	192,571	187,067	322,165
Missouri	33,001	31,616	33,129	46,868
Total	736,540	770,485	770,473	1,215,868
U.S. Total	10,761,296	10,866,258	12,044,931	16,254,167
% of U.S.	6.8	7.1	6.4	8.1

	Value of All Farm Products Sold*			
	1944	1949	1954	1959
Texas	433,940	577,357	484,904	670,312
Colorado	76,452	111,689	71,589	143,783
New Mexico	23,858	38,937	27,718	47,064
Oklahoma	435,575	449,432	390,206	569,713
Arkansas	136,016	113,463	219,366	319,302
Louisiana	77,214	102,035	111,979	143,834
Kansas	383,417	391,106	403,424	603,747
Missouri	32,591	41,241	46,920	61,910
Total	1,616,023	1,830,310	1,756,106	2,561,555
U.S. Total	19,338,028	20,847,933	23,526,115	30,101,003
% of U.S.	8.4	8.8	7.5	8.5

*1,000-1957 dollars.

Manufacturing

Value added by manufacturing in the study area has shown a 356 percent increase (1957 constant dollars) from 1939 to 1958, compared to 166 percent increase in the United States during the same period of time. These trends, shown in Table V-6, indicate the increasing importance of the Ark-Red area in the manufacturing segment of the national economy.

Important components of the manufacturing sector include petroleum, petrochemicals, natural gas, iron and steel, aluminum, pulp and paper, and food and kindred.

Table V-6

Value Added by Manufacturing
(1,000 - 1957 dollars)

	<u>1939</u>	<u>1947</u>	<u>1954</u>	<u>1958</u>
Texas	307,076	813,728	1,350,603	1,716,363
Colorado	44,788	72,394	114,436	140,837
New Mexico	1,716	3,069	4,312	6,854
Oklahoma	204,972	405,051	597,204	635,917
Arkansas	111,427	269,996	433,461	487,902
Louisiana	65,627	140,877	233,673	229,042
Kansas	115,223	301,702	604,431	631,302
Missouri	25,246	42,173	77,306	96,360
TOTAL	876,075	2,030,408	3,415,426	3,995,577
United States	52,934,205	97,907,417	128,241,350	140,817,936
% of United States	1.65%	2.07%	2.66%	2.83%

Petroleum

Since the discovery of important oilfields in eastern Kansas and northeastern Oklahoma nearly 50 years ago, the petroleum industry has been one of the chief sources of area income. In 1960, the study area accounted for about 17 percent of the total U. S. oil reserve.^{5/} Total United States reserves in 1960 were estimated at 38 billion bbl. The ratio of petroleum value to the value of all minerals produced in 1961 for the following States (States with all or most of the mineral industry included in the study area) was: Oklahoma - 94 percent; Arkansas - 68 percent; Kansas - 80 percent.^{14/} Oil refineries in operation in the basin in 1961 had a capacity of 958,000 bbl./day.^{15/} This amounts to about 15 percent of the U. S. capacity. For the year about 277 million barrels (10 percent of the U. S. production) were produced.

Petrochemicals

Development of the oil and gas resources has resulted in location of a significant portion of the petrochemical industry in the study area. Since 1940, this industry has grown from 2 to over 45 plants in the study area.^{16/} Peak production of about 2.5 million tons was reached in 1959.^{17/} This amounted to 3 percent of the total national production.

Natural Gas

The natural gas processing industry has been actively developed in the study area since the turn of the century and is still one of the major sources of income in the area. With three of the Nation's largest gas fields (Hugoton, Panhandle, and Moncove - Richland) encompassed by its boundaries, the study area accounted for 28 percent of the total U. S. reserve (262.6 billion Ft.³) in 1961. ^{6 18/} Thirty-one percent of the U. S. processing capacity (40.5 billion Ft.³/day) is in operation at 176 gas refineries in the study area. ^{19/}

Iron and Steel

The iron and steel industry in the Arkansas and Red River basins has become firmly implanted in two major locations, Pueblo, Colorado, and Lone Star, Texas. With operations dating back almost 88 years, the plants are becoming completely diversified, serving all of the southwest and other parts of the country. The two plants have a steel ingot capacity including expansion now in progress totaling 3.2 million net tons per year. ^{20 23/} Total production in 1961 amounted to approximately 2.1 million tons. ^{22 23/}

Aluminum

Present aluminum production in the Ark-Red basins is confined to Clark and Hot Springs Counties in central Arkansas. Alumina reduction plants, located near Hot Springs and Arkadelphia, have a

capacity of 164,000 tons per year (6.8 percent of the U. S. capacity). ^{24/} Production in 1960 amounted to about 140,000 tons.

Pulp and Paper

The pulp and paper industry is centered in the eastern portion of the study area. Eleven mills, representing 7 percent of all woodpulp mill capacities in the United States are located in Arkansas: 5 mills in Louisiana with combined capacity of 3,785 tons/day; 4 mills in Arkansas with combined capacities of 4,135 tons/day; 1 mill in Oklahoma with a capacity of 50 tons/day; and 1 mill in Texas with a capacity of 40 tons/day. ^{25/}

Food and Kindred

The food and kindred industry includes meat products, dairy products, canned and frozen foods, grain mill products, beverages, and other food preparations. Since the study area has essentially an agriculturally oriented economy, a large portion of the manufacturing is attributable to this industry. In the Ark-Red study area, food and kindred employment in 1959 amounted to 16 percent of all manufacturing employment. ^{26/}

Most of the food processing in the study area is accomplished by small plants serving local populations. In terms of income and employment, however, the major industries of this classification are meat packing, flour milling, canning, and fruit processing, and

poultry processing. Some of these plants are of large scale proportions, such as the meat packing plants in Wichita, Oklahoma City, and Fort Worth; poultry processing plants in northwestern Arkansas; rice processing plants near Stuttgart, Arkansas; and flour mills in Hutchinson and Wichita, Kansas.

Population of the Study Area

Historic trends of the study area population from 1910 through 1960 are summarized by States in Table V-7 and presented by subareas in the Appendix. It will be noted that in addition to total population figures, a "municipal" component is separately presented. This element includes all incorporated places and those unincorporated places with a 1960 population of 1,000 or more. The municipal sector is compiled separately to approximate the population supplied by public water supply systems. This compilation facilitates examining trends and making projections of the population and water requirements expected to be exerted through municipal water systems. Municipal population as used in this report, therefore, is not comparable to urban population as defined by the Bureau of the Census.

In 1960, the study area contained 5 percent of the Nation's population in 9 percent of its continental land area. In the period 1910-1960, the national population increased 95 percent compared to

Table V-7
Summary of Study Area Population Trends 27/

Study Area Within State of:	Population Component	1910	1920	1930	1940	1950	1960
Colorado	Municipal	146,797	149,182	164,750	179,571	212,004	280,109
	Total	261,810	293,576	305,370	301,970	325,195	407,836
New Mexico	Municipal	19,561	27,511	35,354	46,137	61,890	64,867
	Total	89,760	97,256	95,219	101,348	99,701	96,214
Kansas	Municipal	370,022	467,133	540,215	542,097	634,295	777,869
	Total	810,685	881,114	938,714	895,479	950,819	1,067,007
Oklahoma	Municipal	551,101	829,286	1,116,981	1,149,979	1,366,102	1,677,022
	Total	1,652,786	2,028,293	2,422,481	2,335,429	2,233,241	2,328,184
Texas	Municipal	446,877	698,072	988,770	1,110,565	1,647,537	2,479,785
	Total	1,384,905	1,681,478	1,953,809	2,090,732	2,421,318	2,983,218
Missouri	Municipal	100,098	94,033	94,442	100,952	105,106	112,820
	Total	224,719	206,194	199,240	208,370	198,415	189,801
Arkansas	Municipal	294,407	372,074	452,111	487,921	645,725	723,826
	Total	1,163,843	1,273,426	1,316,911	1,370,263	1,340,296	1,297,311
Louisiana	Municipal	107,358	155,003	242,009	296,811	404,220	547,718
	Total	547,896	619,216	754,287	841,325	866,882	963,544
Study Area Totals	Municipal	2,044,221	2,792,296	3,634,642	3,914,633	5,076,879	6,664,016
	Total	6,136,404	7,080,553	7,986,031	8,144,916	8,435,867	9,333,115

a 52 percent increase for the study area. These increases expressed in terms of average annual growth rates are $1 \frac{3}{8}$ percent and $27/32$ percent, respectively. The comparatively low growth rate in the study area was the result of internal migration of the rural population to the city. This steady stream of new labor supply took over jobs that might otherwise have brought about immigration from other areas to serve this budding industrial complex.

The change from a rurally to a municipally oriented population is pointed up by the growth trends from 1910 to 1960. During this period, the municipal population grew at the annual rate of $2 \frac{3}{8}$ percent (changing from 33 to 71 percent of the study area population) while the nonmunicipal declined at $7/8$ percent.

Municipal population trends are of particular concern in an analysis of water requirements, since metropolitan areas are centers of large water requirements, both domestic and industrial. The proportion of the population in study area SMSA's* has increased as indicated in Table V-8. Study area SMSA populations grew 620 percent during this period (1910-1960), while the national SMSA population increased 215 percent. Study area SMSA's represented almost 4 percent of the national SMSA population in 1960 as compared with less than 2 percent in 1910.

*Standard Metropolitan Statistical Area - A central city with a population of 50,000 or more and its urbanized fringe area.

Table V-8

Population Trends in the Study Area and the Nation ^{28/}
(Millions)

	Population Component	1910	1920	1930	1940	1950	1960
Study Area:	Total	6.1	7.1	8.0	8.1	8.4	9.3
	SMSA*	0.6	1.2	1.8	2.1	3.1	4.3
	% of Total	9.8	16.9	22.5	26.0	38.0	46.3
United States	Total	92.2	106.0	123.2	132.2	151.3	179.3
	SMSA*	35.3	47.2	62.3	68.1	85.8	111.2
	% of Total	38.3	44.5	50.5	51.5	56.7	62.0

*SMSA population for all decades adjusted to include geographic area defined as SMSA's in 1960.

Economic Growth

Economics

Regional progress is directly related to national development. Although various regions of the United States differ in production and available resources, they are interrelated by flows of goods and services throughout the Nation. Assuming the national economy continues to grow in the future as it has in the past, the Ark-Red study area will participate in that growth. What share the region can claim will be determined by its ability to compete with other areas of the United States in the production of goods and services. Therefore, all projections made for the study area are keyed to national projections.

Over the past 30 years, this area has increased its output at a faster rate than the Nation as a whole. This is evidenced by the higher rate of growth of personal income in the region compared

to corresponding U. S. figures. The trend of increasing personal income is expected to continue in the future as resource development and industrial expansion occur.

As has been the experience in other parts of the country, extensive development of inland waterways in the area will offer not only economical transportation, but will open new markets, both in the United States and abroad. These markets were previously inaccessible because of transportation costs. At the present time navigation projects have been authorized for canalization of the Arkansas River to the Tulsa vicinity and the Red and Ouachita Rivers in Arkansas and Louisiana. Projects are proposed for navigation canals on the Red River to Denison, Texas, the Trinity River to Fort Worth, and the Central Oklahoma project to Oklahoma City.

With the transfer of NASA operations to Houston, the western tip of the Gulf Coast "Space Age Crescent" (Canaveral to Houston) has become the center of activity for this newest of man's great enterprises. Proximity of the Ark-Red study area to this budding industry has already been felt in buildup of many new industries to supply space exploration needs. As the space industry grows to maturity, other needs will develop and with the many advantages the Ark-Red area has to offer, it should logically become a center of production to meet some of these needs.

The area's climatic advantages form an attraction for "foot-loose industries" which can locate without considering resources or market availability. Such industry usually finds the needed labor force has already recognized the climatic advantage. This is true in the study area, since the labor force is available to accommodate industrial expansion. The mobility of labor within the study area allows movement of people to areas where industry develops.

Extractive Industries

Minerals

The study area is rich in mineral reserves. This is especially true of natural gas and petroleum. With 28 percent of the U. S. gas reserve and 17 percent of the Nation's petroleum reserve in the area, plus the addition of future discoveries, petroleum and natural gas extraction are expected to remain the leading extractive industries in the study area for many years.

Forestry

The forest industry in the eastern portion of the study area is expected to continue trends of devoting more land to softwoods with less land being utilized for hardwood. Pulpwood produced by these forests will be valuable to the pulp and paper industry in the future.

Agriculture

Agriculture in the study area is expected to hold its favorable competitive position in respect to other regions of the United States in production of food and fibers. Improved technology and demand for agricultural products will prompt a shift to more specialized, higher value crops and livestock programs. This shift will take place with the aid of increased acres of irrigated land, especially in the eastern portion of the study area. Irrigation will stabilize the farm economy and allow the irrigator to make more efficient use of seed, fertilizer, equipment, and labor. Projections of irrigation appear in Appendix - Exhibit D.

Manufacturing

Expectations are for continued growth of manufacturing in the study area. Specific studies of major water using industries appear in Appendix - Exhibit C.

As demands from local markets increase and low cost barge transportation is made available, major oil refining centers now in the basins are expected to expand. In order to help meet the expected increase in the national demand for petroleum products, in the year 2020 a production of 1.2 billion barrels per year is projected for the study area.

While much of the past petrochemical production in the Ark-Red basins has been largely for markets outside the basins, future production will be directed more toward local markets. This change in trend should come about as the industry, which is presently concentrated in the southwest, becomes more evenly distributed throughout other areas of the country. The projected study area yearly production to the year 2020 is 19.4 million tons, about 5 percent of the projected national production.

Since there are prospects that natural gas will have difficulty in the future competing with other fuels such as coal and fuel oil, many authorities believe that a peak in production will be achieved by 1980.^{5 29/} New gas discoveries are currently found at much greater depths than in the past and in recent years new additions to reserves have not been keeping pace with increases in demands.

As a base for projecting future growth in the basins, it is assumed that the industry will continue to expand through 1980 near the rate projected for the Nation in the Senate Select Committee Print No. 8.^{30/} Fuel requirements after this time may be supplemented by various sources of energy. Further progress in coal gasification and recovery of gas from oil shale reserves may exert significant influence on the gas processing industry.^{16 31/}

While the discovery of new gas fields may require relocating present facilities or building new gasoline plants, present major study area gas processing sites are expected to remain the leading areas in the future.

Major future expansion of the iron and steel industry in the study area is expected to originate at present production centers with growth rates paralleling projected national expansion rates. Recognition should be given to bituminous coal reserves in southeastern Oklahoma as a possible future location for limited iron and steel production. Increased demands for steel in central and northern Oklahoma may result in the location of a small plant on the Arkansas near these growing market areas.

To meet a prorated share of the national 2020 demand for iron and steel products, 7 million tons per year are projected for the study area.

Major expansion in the U. S. aluminum industry is expected to take place in areas such as the Gulf Coast which are favorably located for importation of bauxite and also have the power potential by virtue of natural gas and lignite of the region. However, as limited local bauxite reserves are depleted, new supplies may be obtained to sustain present production levels from foreign imports by way of the authorized Arkansas River Navigation Project. ^{32/}
Future aluminum production in the basins is, therefore, expected to remain at or near the present level of production.

Future growth of the pulp and paper industry in the study area is expected to parallel the national growth trends projected by the U. S. Forest Service. ^{33/} Assuming the study area will continue producing about 5 percent of the Nation's demand, the 2020 output is expected to be 4½ million tons.

The food and kindred industry in the study area is generally located near metropolitan areas with production largely based on local demands. In portions of the study area, industries have located near the source of agricultural products and are the nucleus of future food processing centers. These centers, while serving other parts of the Nation, will aid in developing local agricultural areas.

Population

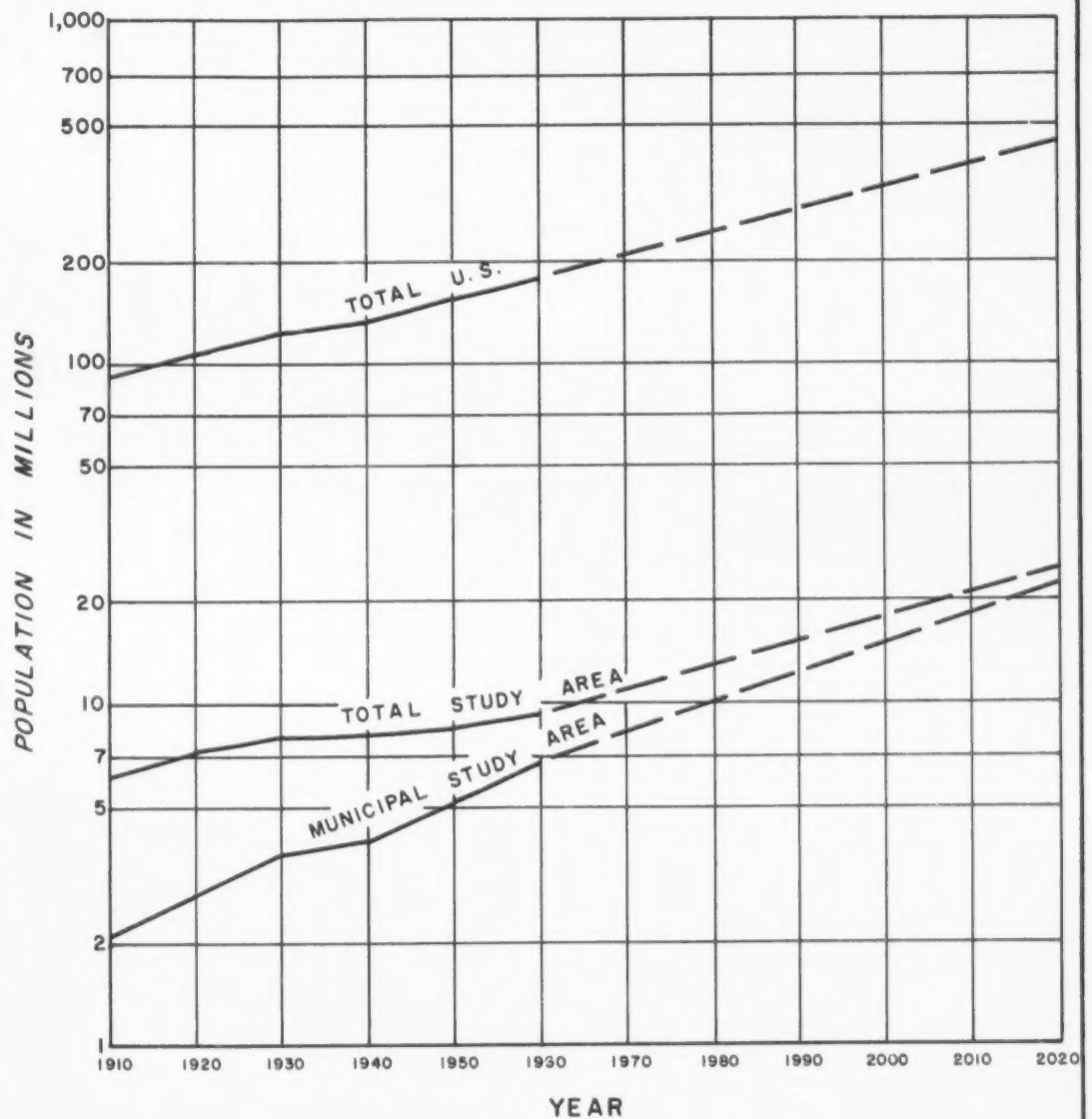
Considering the relative past and future economic position of the study area outlined in previous sections and the historic population trends, a projection is made for the study area population to the year 2020. These many factors are weighed in relation to the Nation's past performance and future prospects to establish the region's potential for population growth.

The most likely national population in 2020 is considered to be an extrapolation of the 2000 middle range population prepared for the Senate Select Committee by Resources for the Future. ^{34/} This

establishes a 2020 population of 440 million for the Nation. An analysis of the overall study area potential in relation to its competitive position in the Nation resulted in a 2020 population allocation of 24.47 million of the national projection to the Ark-Red area. Historic trends and projections are depicted in Figure V-3.

Having established a total study area population for 2020, the next and most difficult step involves developing individual allocations for each of the 82 subareas to facilitate projections of municipal water requirements. First, cognizance is taken of the effects of the region's transition from agrarian to industrial economy, and the municipal component of the total population is projected separately based upon the assumed future relationship of municipal to rural dwellers. As a result, the projected 2020 study area municipal population of 22.378 million is derived. (See Figure V-3) To accomplish the actual breakdown of population into subareas, each subarea is classified on the basis of the 1960 population into Rural, Population Center, and SMSA categories, as previously defined.

The 12 subareas containing at least one SMSA are examined first, since SMSA's presently account for almost one-half of the study area population and well over one-half of the national population (Table V-8). Projection of the national SMSA population to 2020 by Torget's Statistical Method ^{28/} indicates approximately 80 percent of the Nation's populace will reside within SMSA's. (See



ARKANSAS-RED RIVER BASINS
WATER QUALITY CONSERVATION PROJECT-
BENEFITS EVALUATION

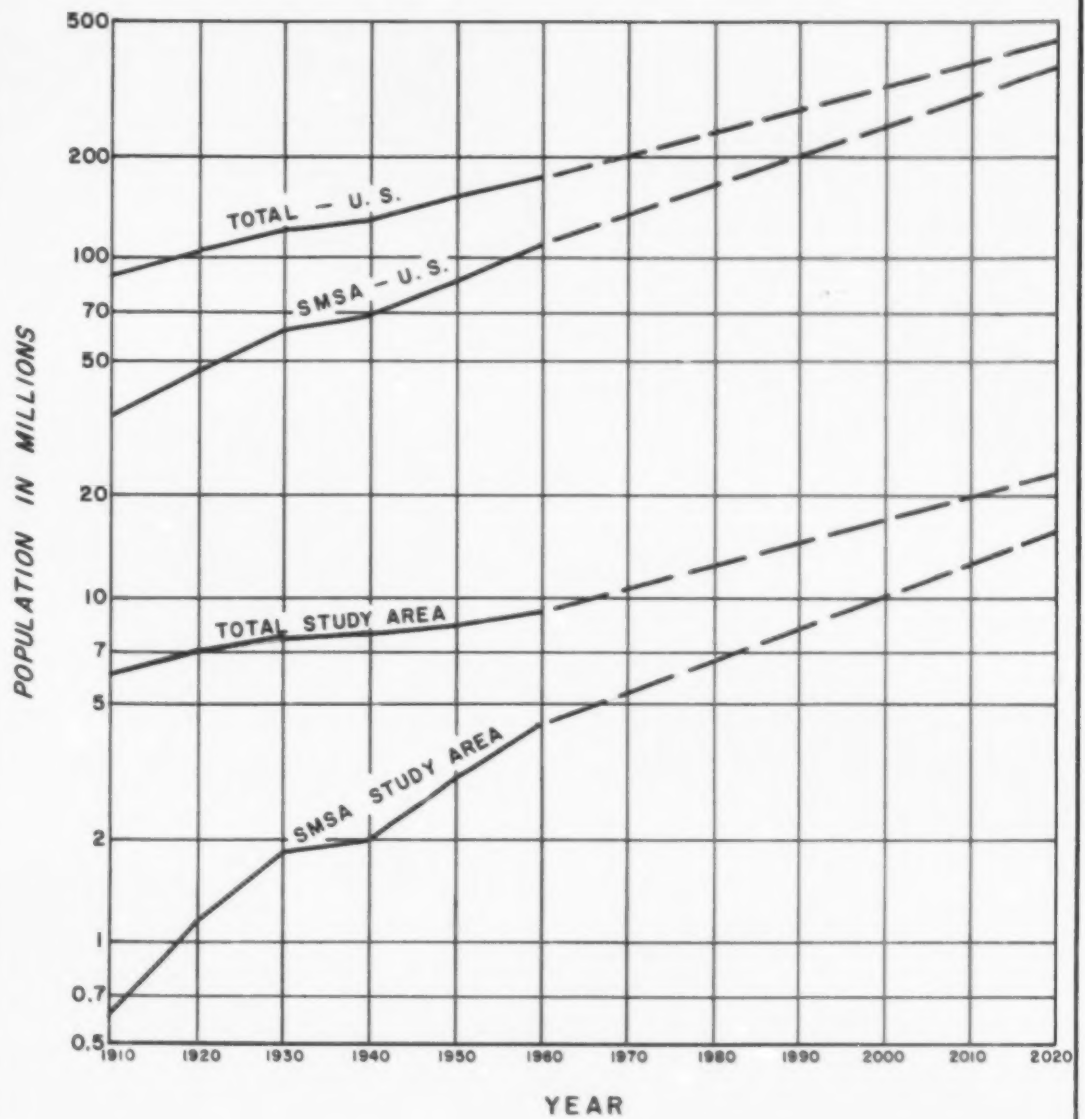
POPULATION TRENDS NATIONAL AND STUDY AREA

DEPARTMENT OF HEALTH, EDUCATION, & WELFARE
PUBLIC HEALTH SERVICE
REGION VII DALLAS, TEXAS

FIGURE V-3

Figure V-4.) From examination of the economic base and historical population trends of study area SMSA subareas, in relation to the entire study area, projections are developed for each. Historically, study area SMSA population has increased at a more rapid rate than the national SMSA population. However, as the population base of an SMSA expands, the rate of growth tends to decrease ^{28/} even though numerical increases may be constant or even increasing. This phenomenon is illustrated by the total study area SMSA population projection shown in Figure V-4. The projected 2020 population of the 12 SMSA subareas totals 17.2 million or about 70 percent of the projected study area population. Individual projection for these subareas are presented in Figures V-5 through V-16.

Those subareas classified as Population Centers are the potential SMSA's of the future; therefore, their competitive position in the study area is analyzed next and population projection prepared for these 30 subareas. The remaining projected study area population is allocated to the 40 Rural subareas following examination of their relative potential to support growth. Historic and projected distribution of population by subarea type is shown in Table V-9. Historic trends and 2020 projections for all subareas are presented in Table V-10.



ARKANSAS-RED RIVER BASINS
WATER QUALITY CONSERVATION PROJECT -
BENEFITS EVALUATION

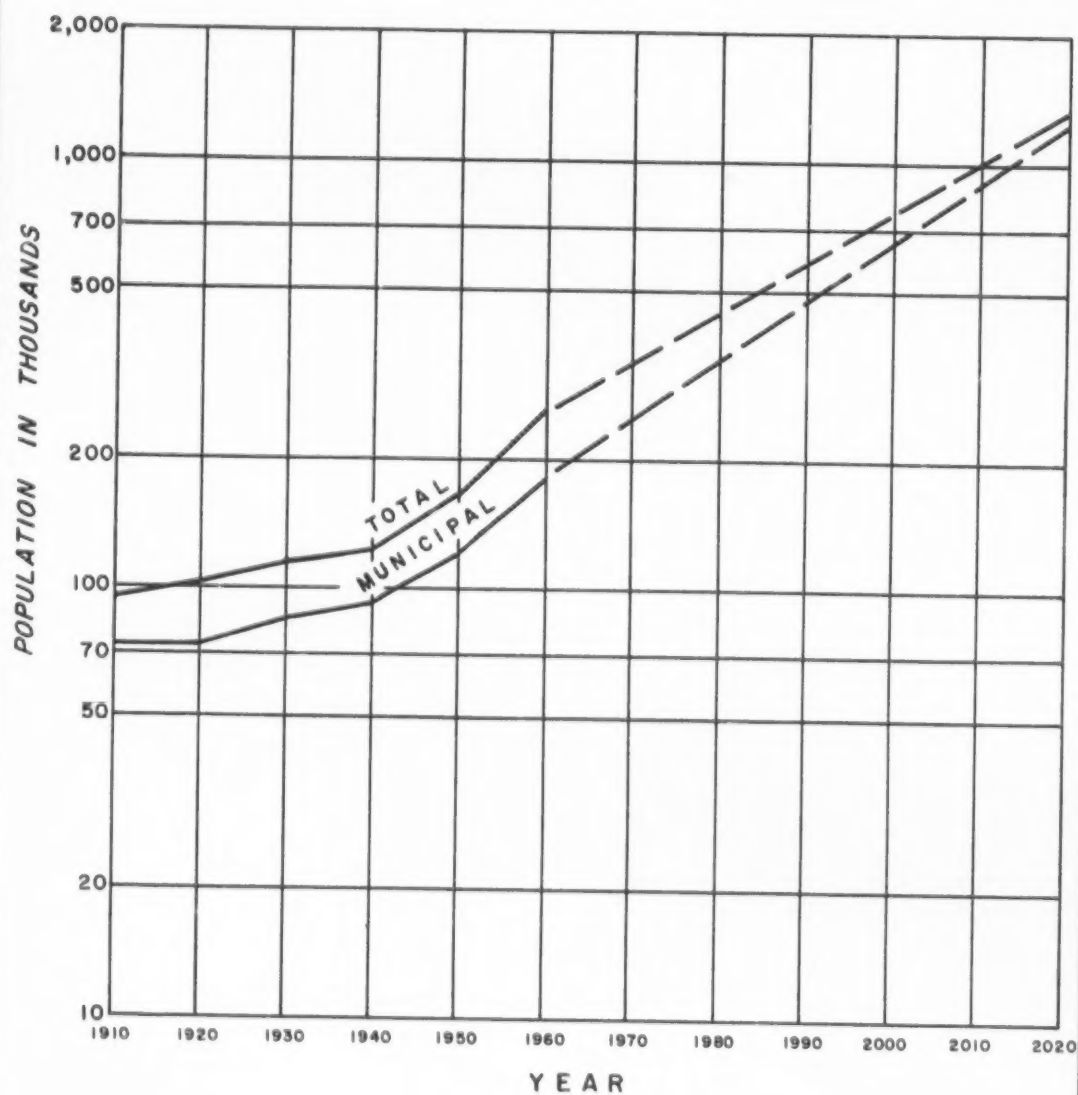
POPULATION TRENDS TOTAL AND SMSA

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PUBLIC HEALTH SERVICE

REGION VII

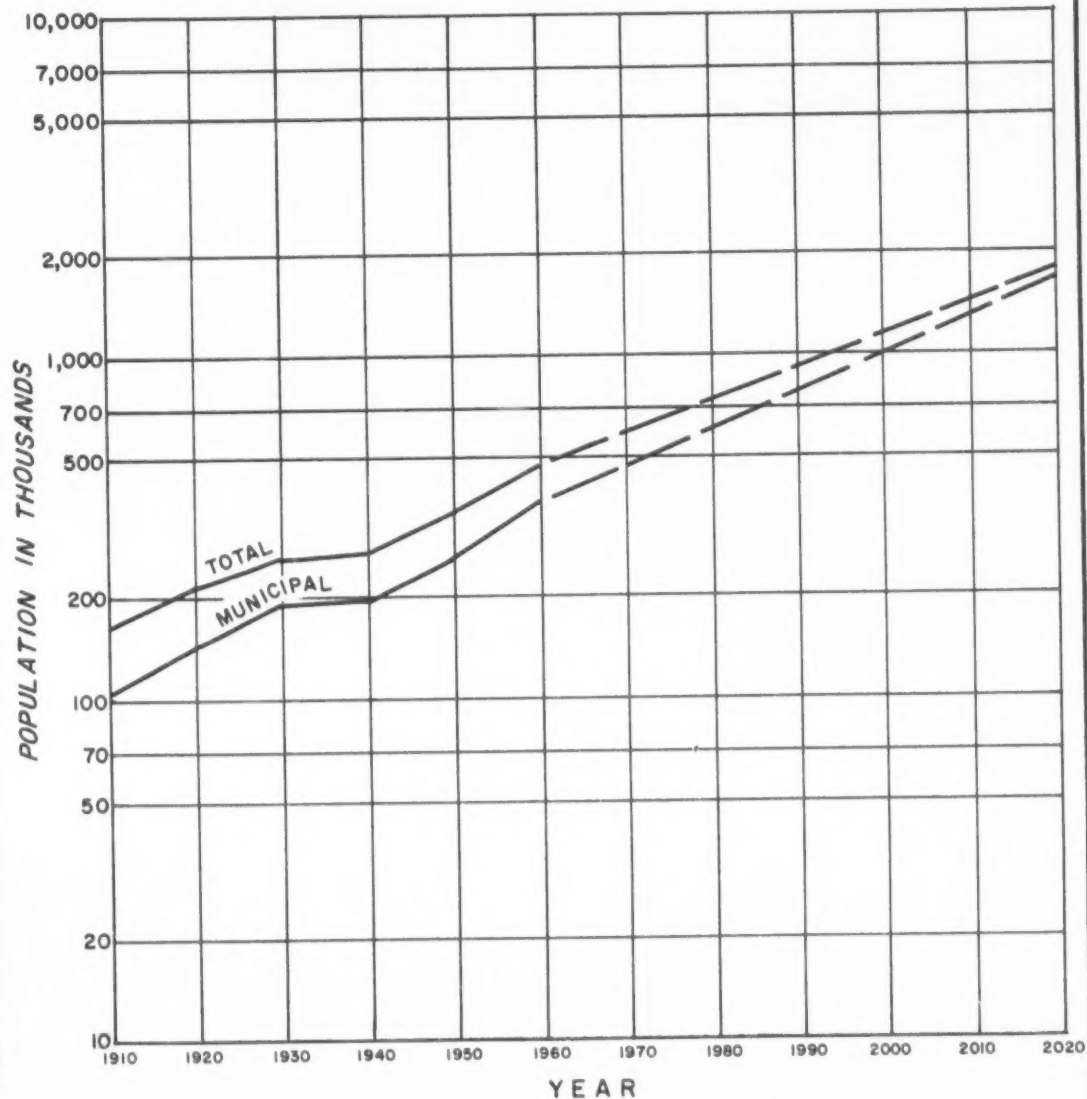
DALLAS, TEXAS

FIGURE V-4



ARKANSAS-RED RIVER BASINS
WATER QUALITY CONSERVATION PROJECT-
BENEFITS EVALUATION
POPULATION TRENDS
PUEBLO-COLORADO SPRINGS SMSA C-1
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FIGURE V-5

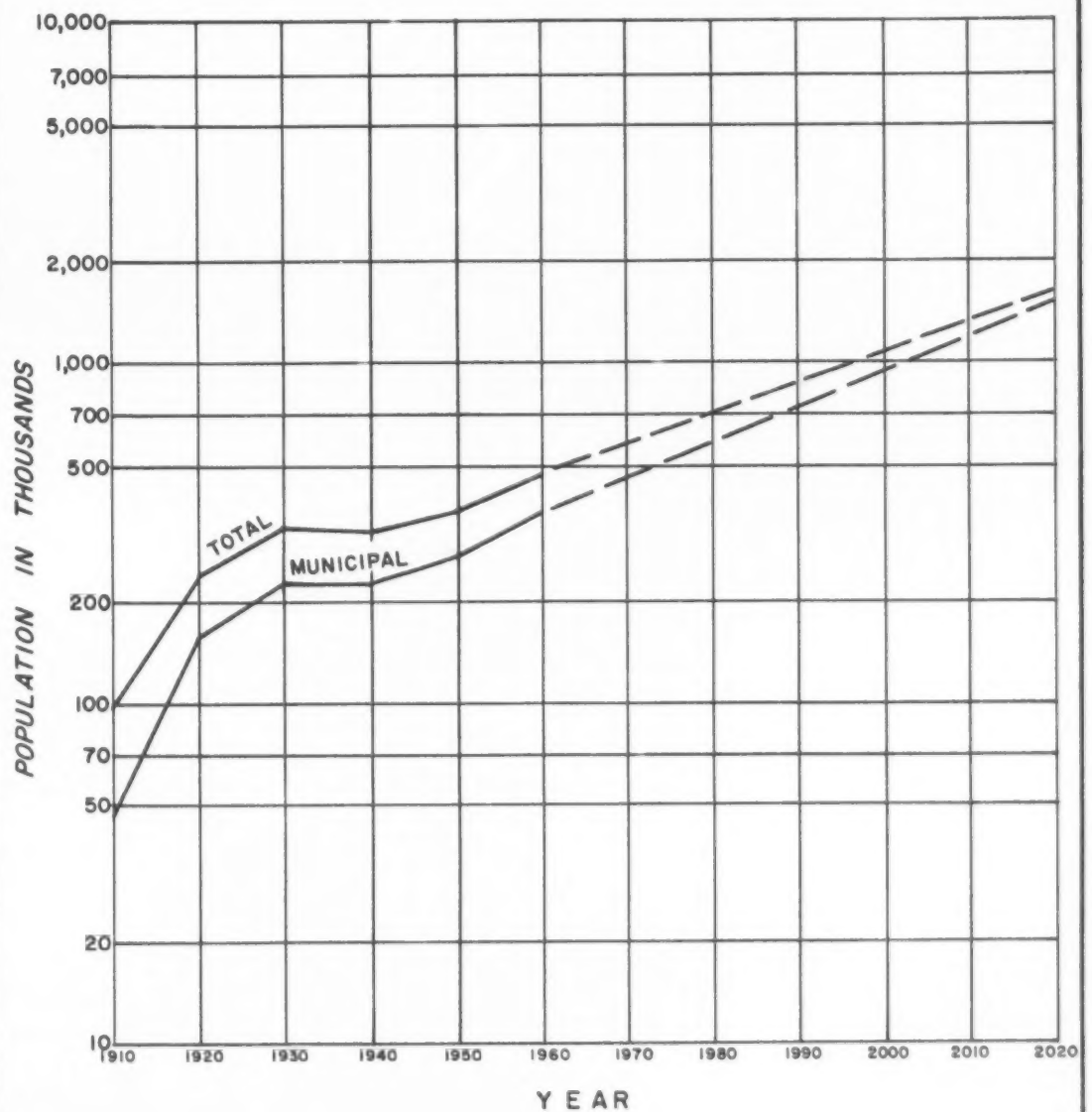


ARKANSAS-RED RIVER BASINS
WATER QUALITY CONSERVATION PROJECT-
BENEFITS EVALUATION

POPULATION TRENDS
WICHITA SMSA K-8

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FIGURE V-6



ARKANSAS-RED RIVER BASINS
WATER QUALITY CONSERVATION PROJECT-
BENEFITS EVALUATION

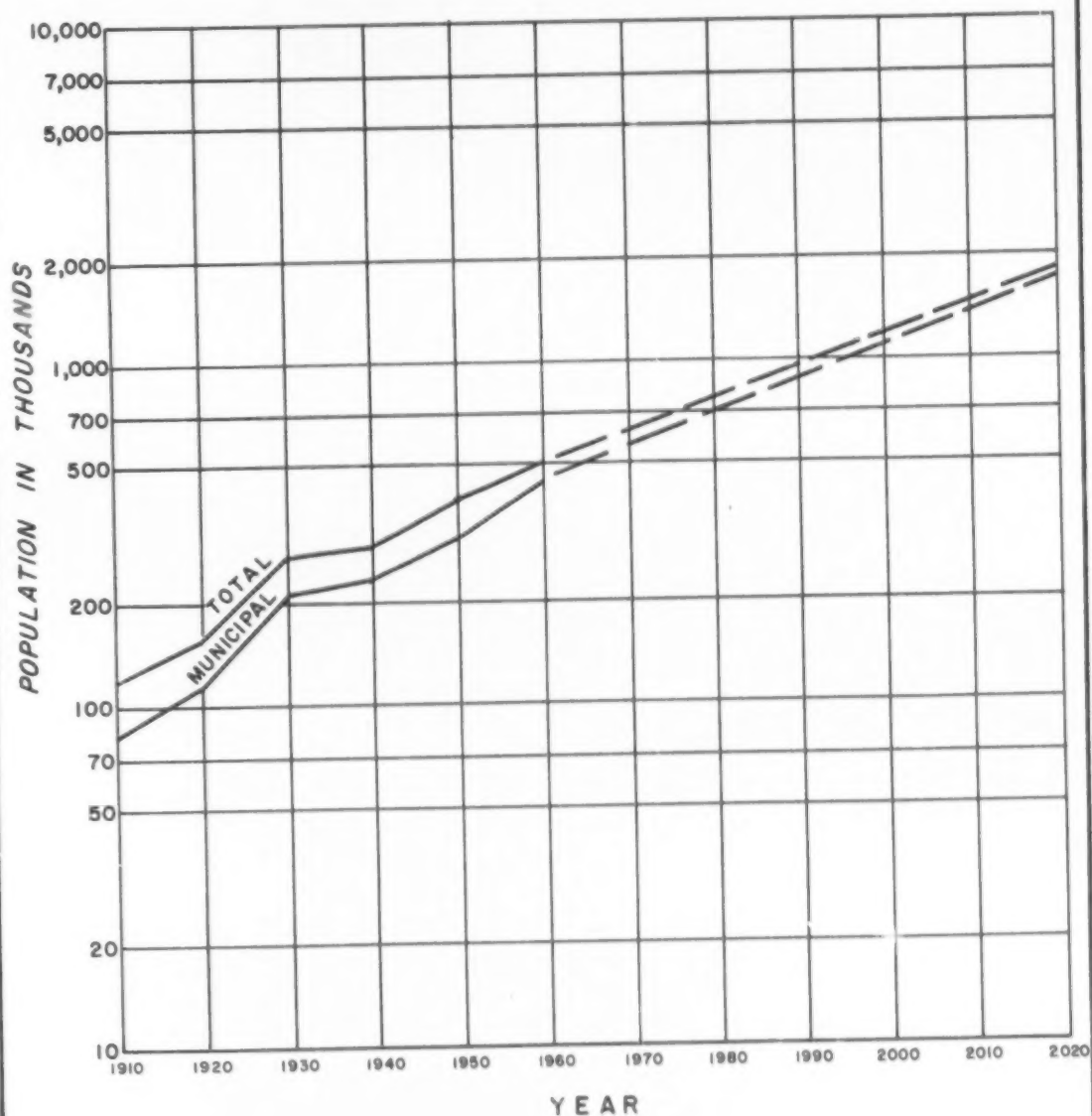
POPULATION TRENDS
TULSA SMSA 0-6

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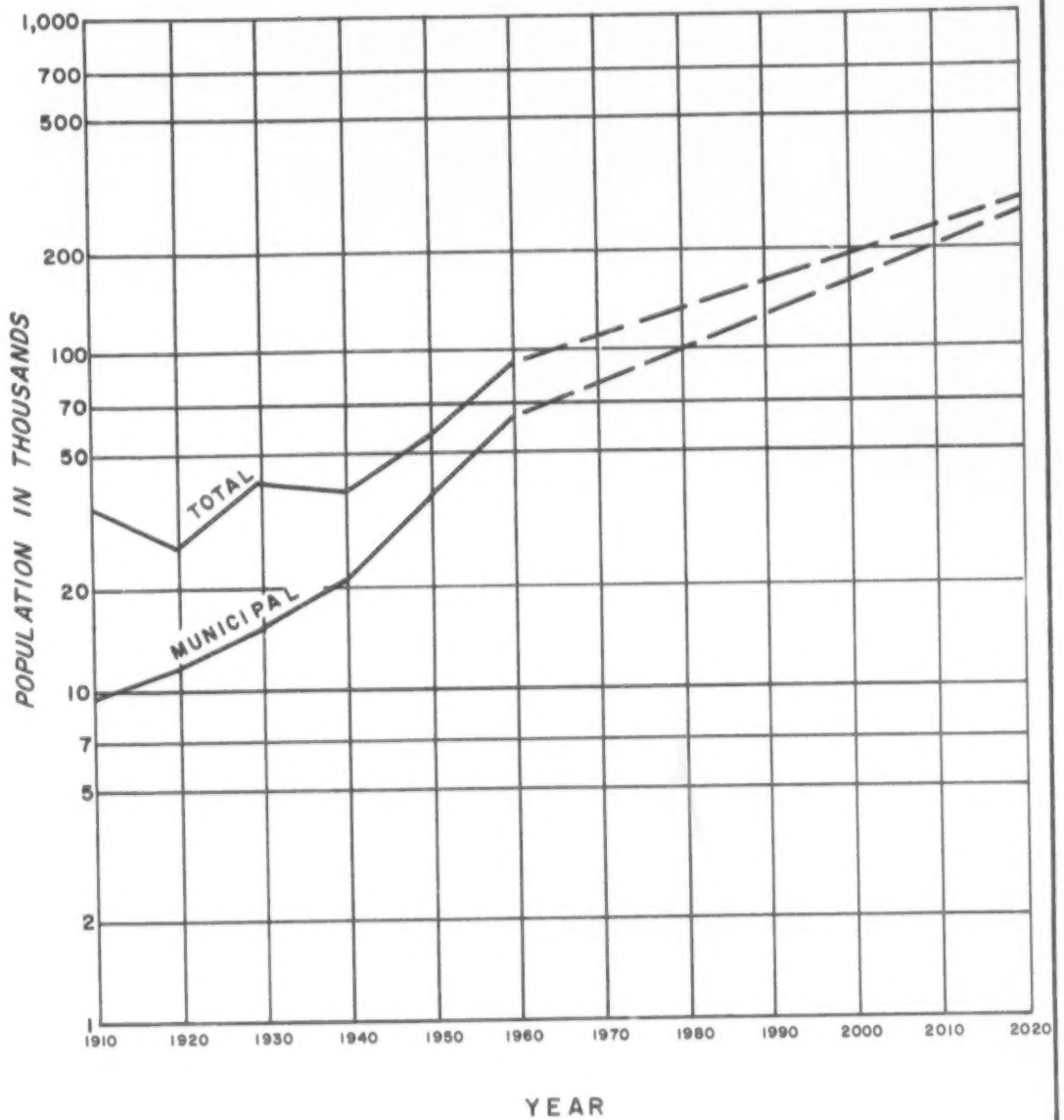
DALLAS, TEXAS

FIGURE V-7



ARKANSAS-RED RIVER BASINS
WATER QUALITY CONSERVATION PROJECT-
BENEFITS EVALUATION
POPULATION TRENDS
OKLAHOMA CITY SMSA O-8
DEPARTMENT OF HEALTH, EDUCATION, & WELFARE
PUBLIC HEALTH SERVICE
REGION VII DALLAS, TEXAS

FIGURE V-8

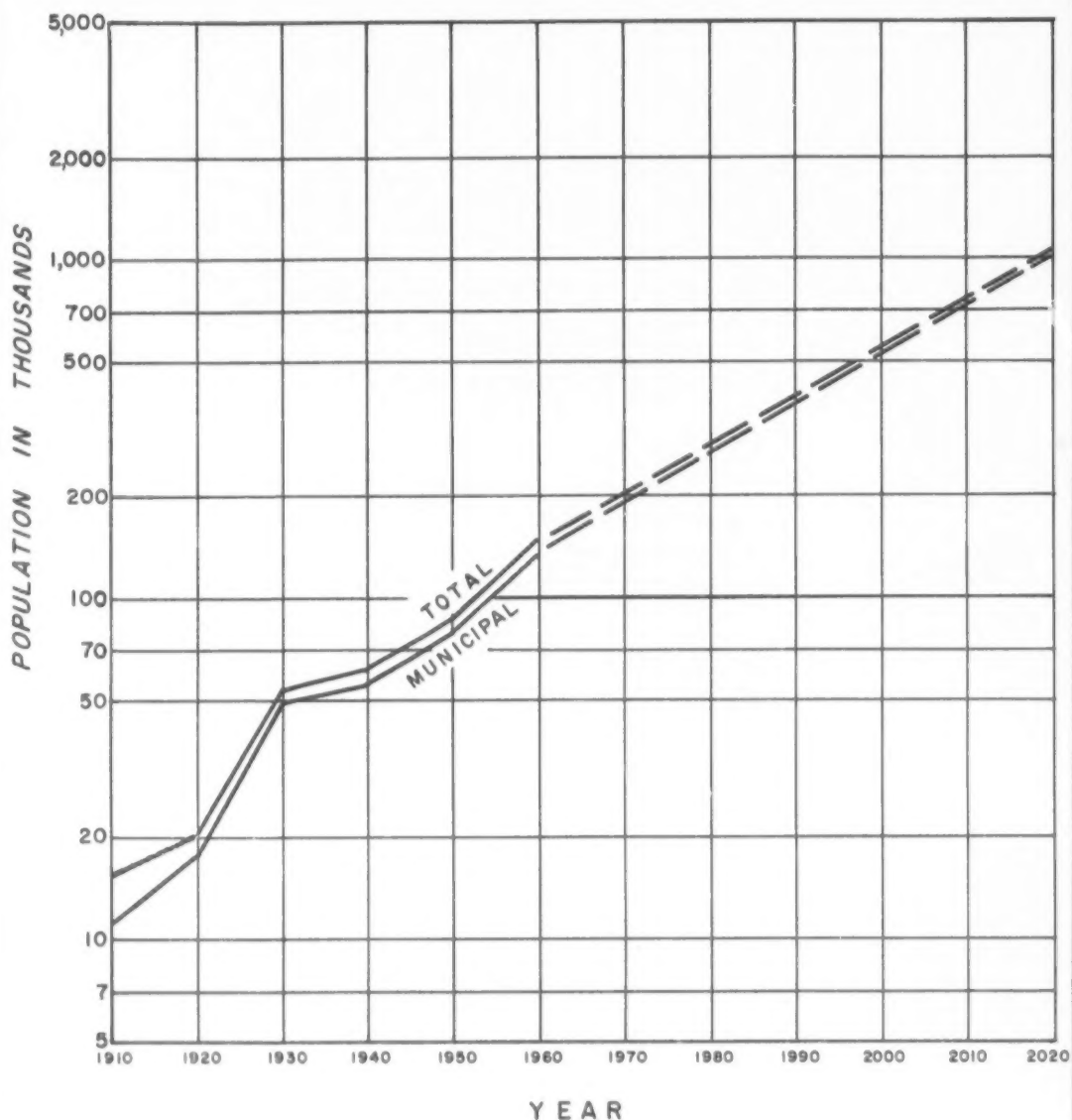


ARKANSAS-RED RIVER BASINS
WATER QUALITY CONSERVATION PROJECT-
BENEFITS EVALUATION

POPULATION TRENDS
LAWTON SMSA 0-10

DEPARTMENT OF HEALTH, EDUCATION, & WELFARE
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FIGURE V-9

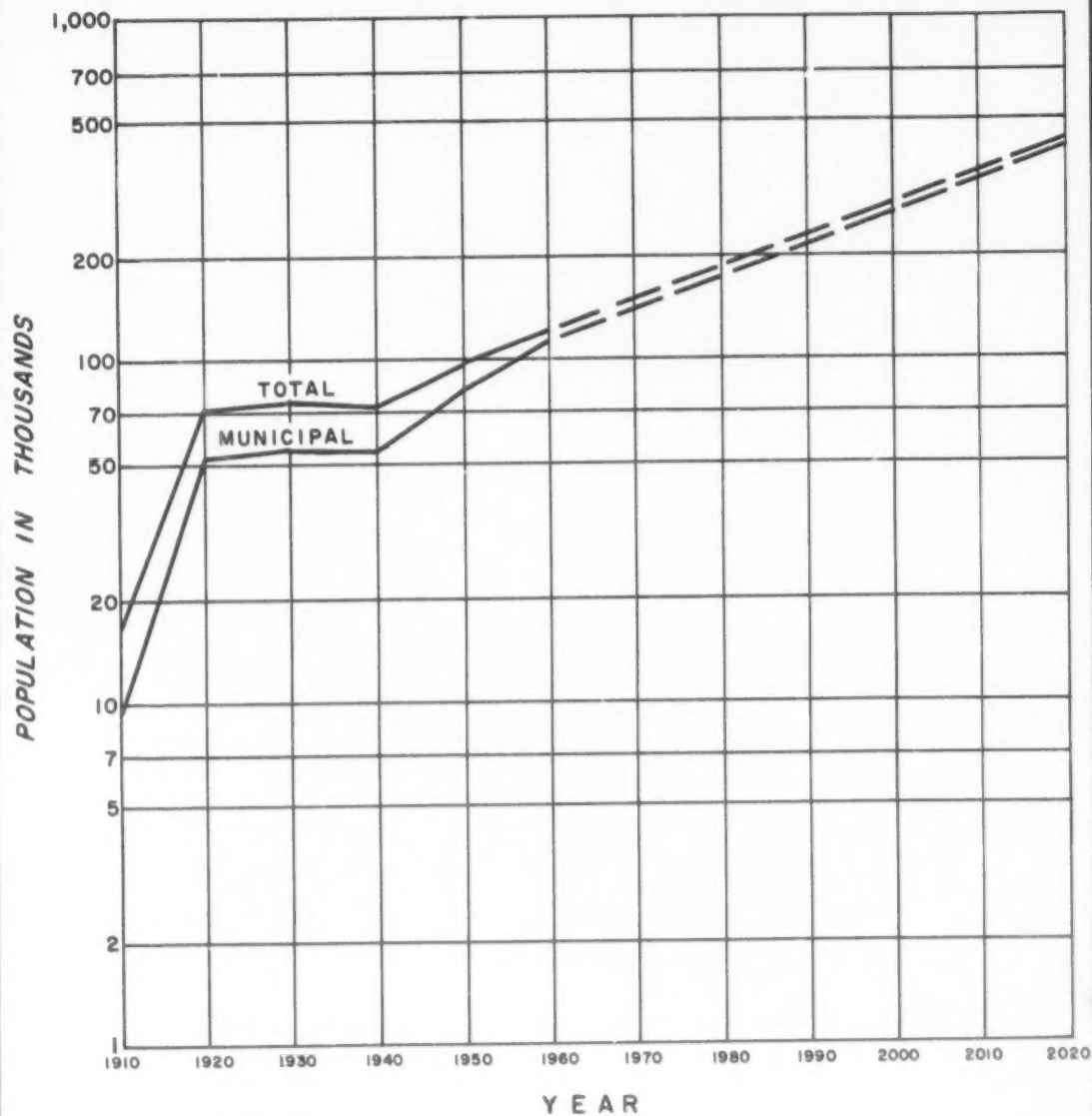


ARKANSAS-RED RIVER BASINS
WATER QUALITY CONSERVATION PROJECT-
BENEFITS EVALUATION

POPULATION TRENDS
AMARILLO SMSA T-2

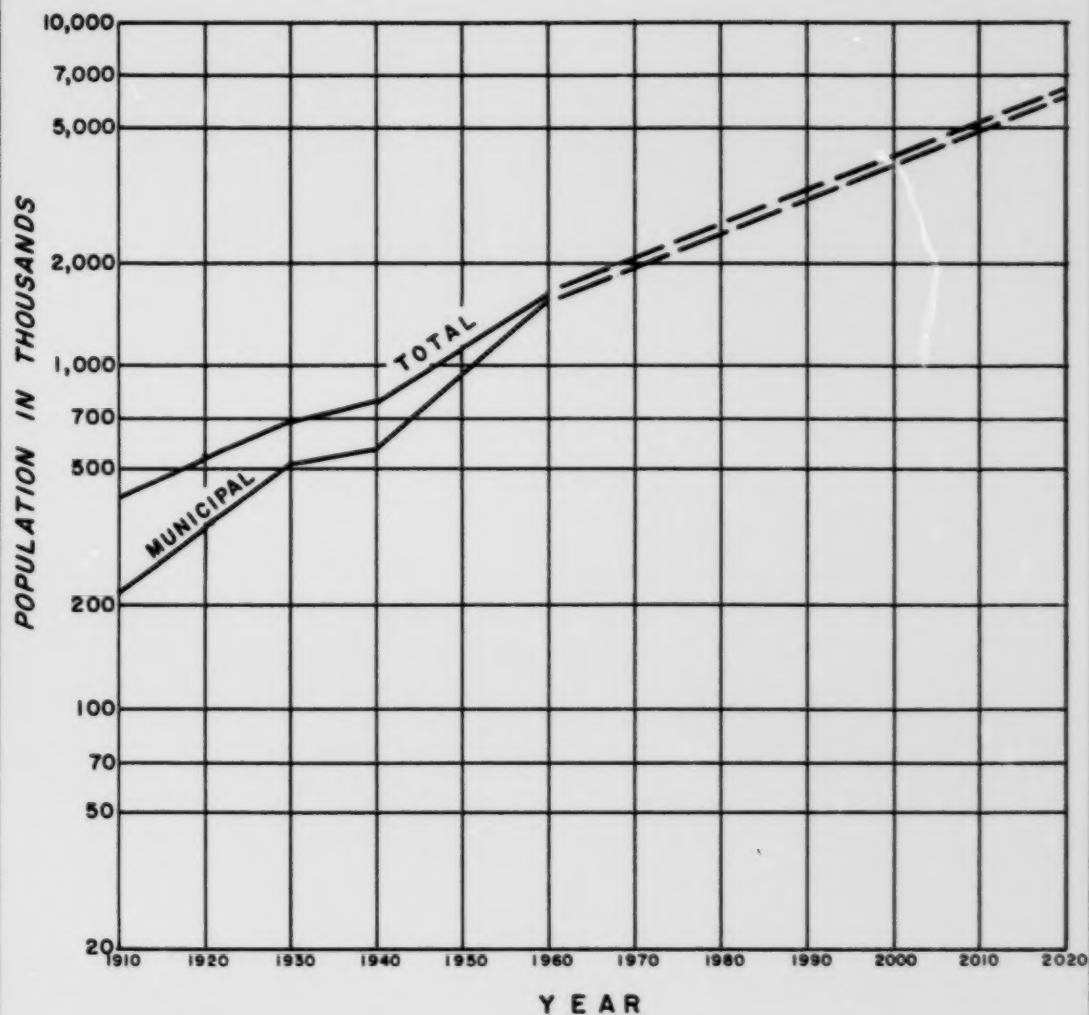
DEPARTMENT OF HEALTH, EDUCATION, & WELFARE
PUBLIC HEALTH SERVICE
REGION VII DALLAS, TEXAS

FIGURE V-10



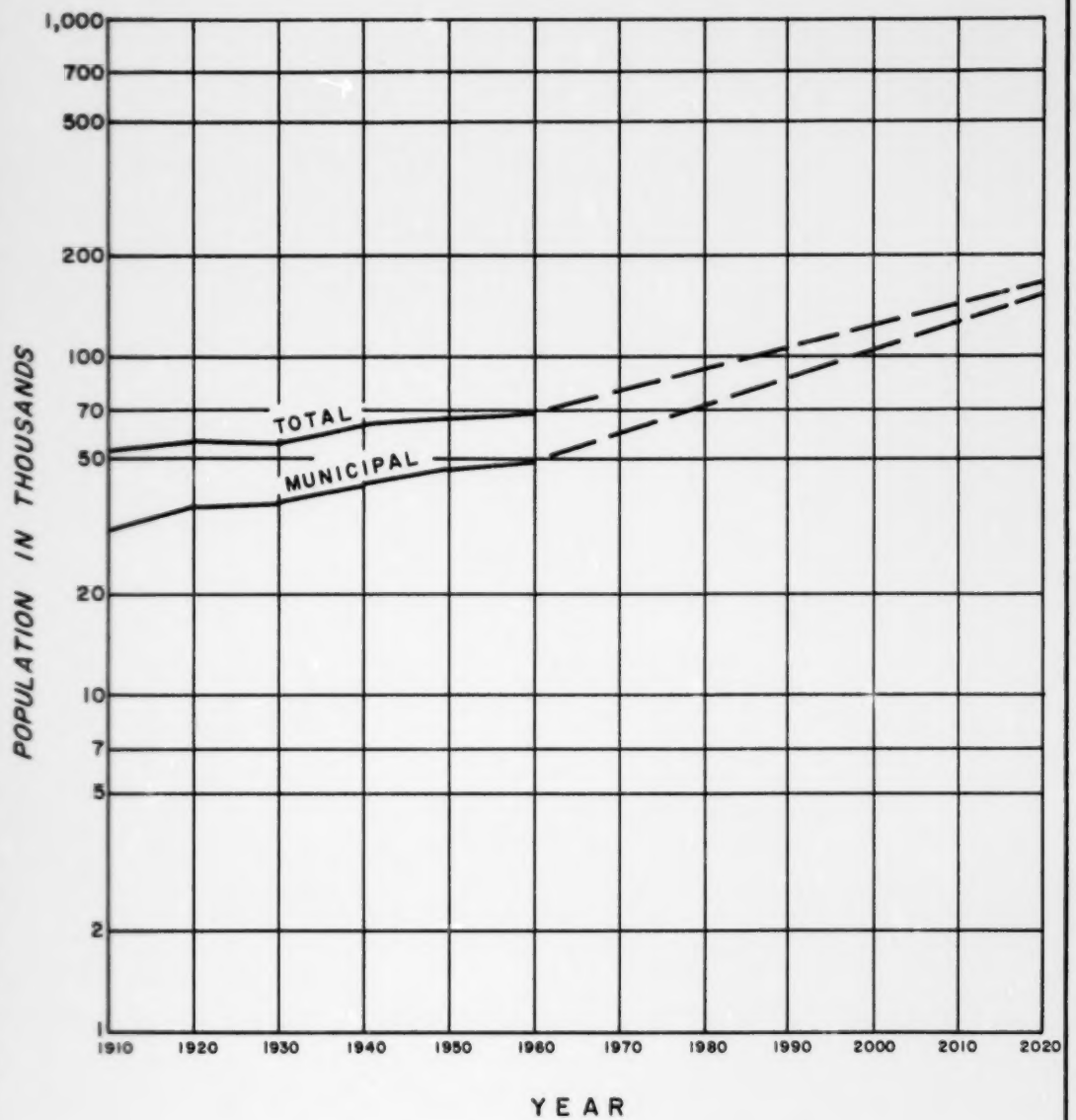
ARKANSAS-RED RIVER BASINS
WATER QUALITY CONSERVATION PROJECT-
BENEFITS EVALUATION
POPULATION TRENDS
WICHITA FALLS SMSA T-8
DEPARTMENT OF HEALTH, EDUCATION, & WELFARE
PUBLIC HEALTH SERVICE
REGION VII DALLAS, TEXAS

FIGURE V-11



ARKANSAS-RED RIVER BASINS
 WATER QUALITY CONSERVATION PROJECT-
 BENEFITS EVALUATION
 POPULATION TRENDS
 DALLAS-FT. WORTH SMSA T-12
 DEPARTMENT OF HEALTH, EDUCATION, & WELFARE
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 REGION VII DALLAS, TEXAS

FIGURE V-12



ARKANSAS-RED RIVER BASINS
WATER QUALITY CONSERVATION PROJECT-
BENEFITS EVALUATION

POPULATION TRENDS

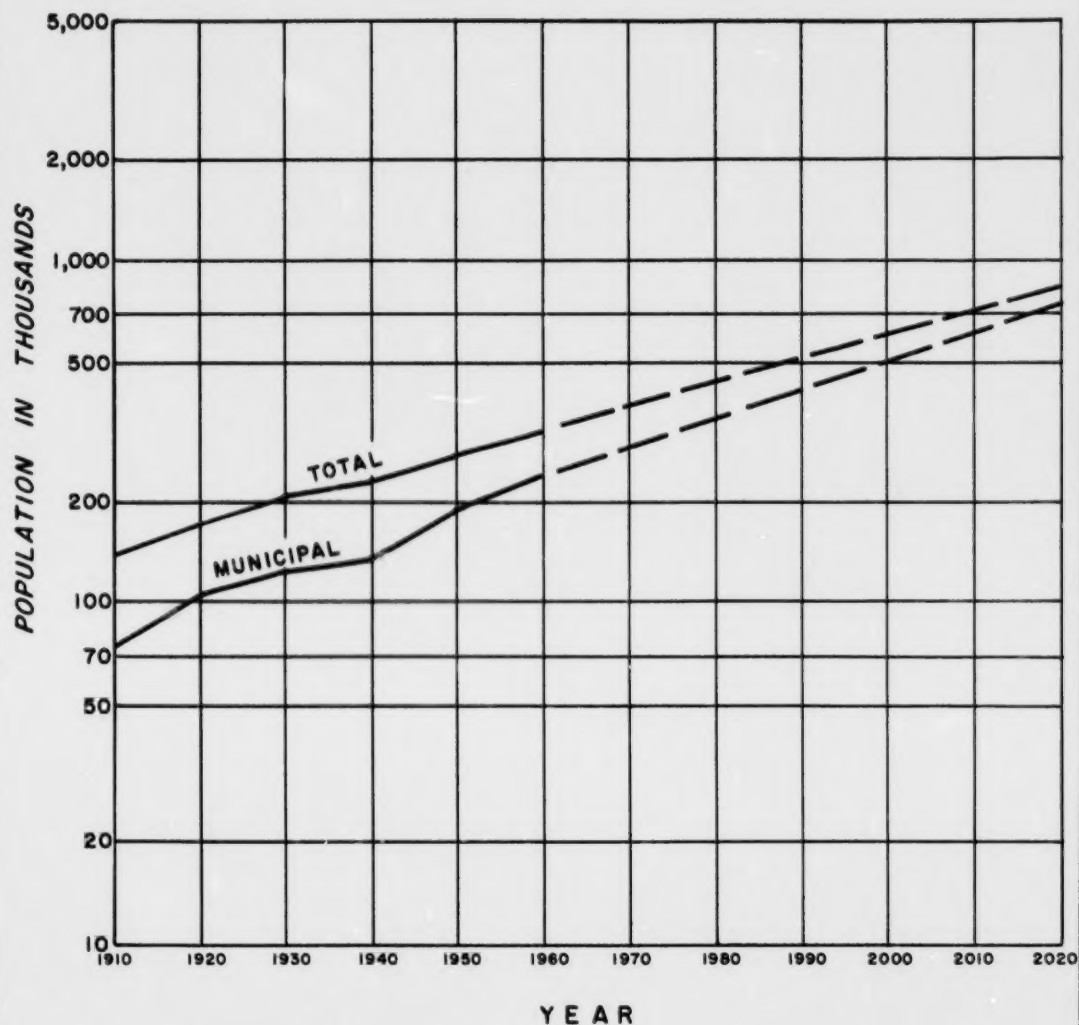
FT. SMITH SMSA A-4

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REGION VII

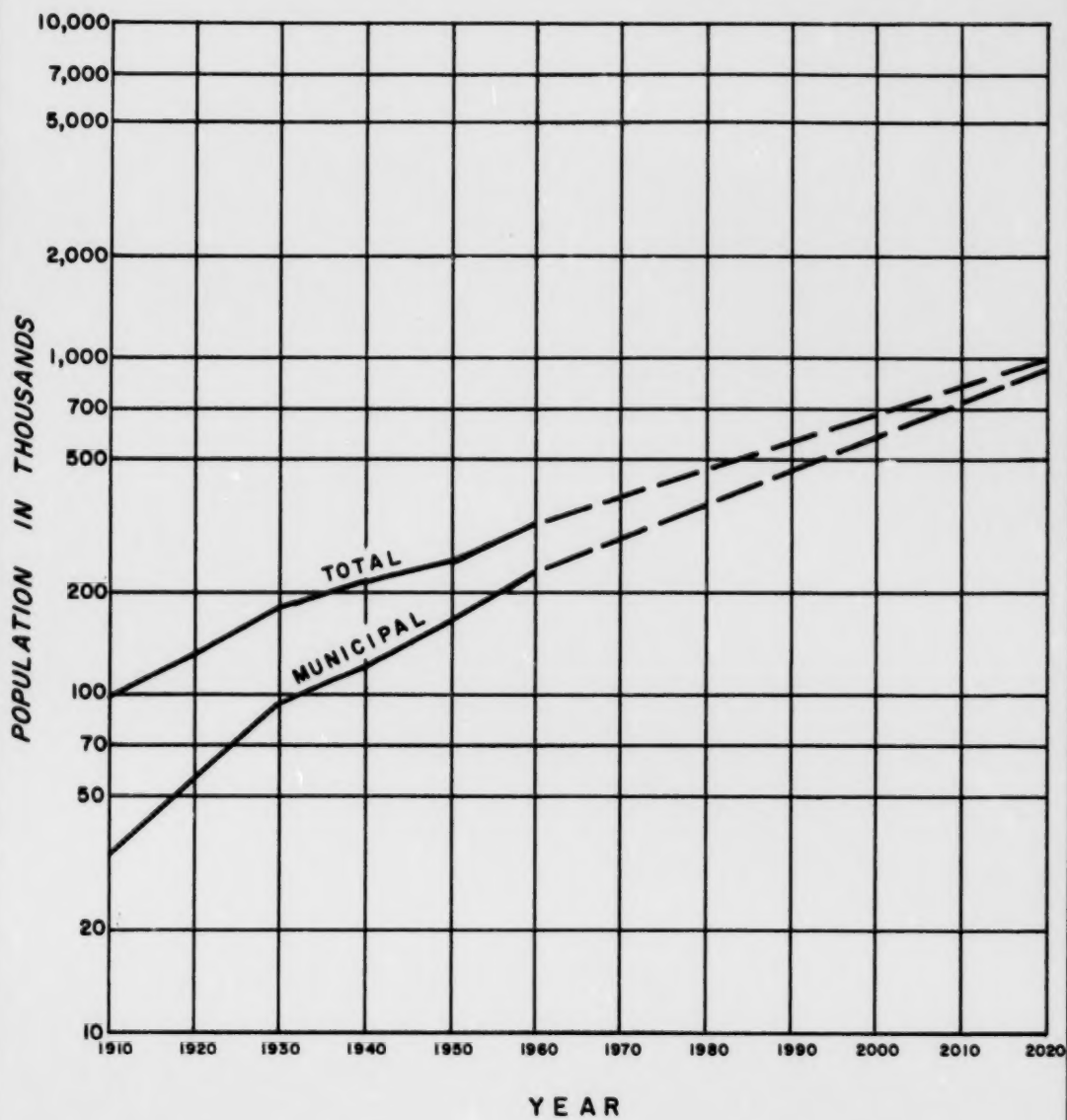
DALLAS, TEXAS

FIGURE V-13



ARKANSAS-RED RIVER BASINS
 WATER QUALITY CONSERVATION PROJECT-
 BENEFITS EVALUATION
POPULATION TRENDS
 LITTLE ROCK SMSA A-7
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FIGURE V-14

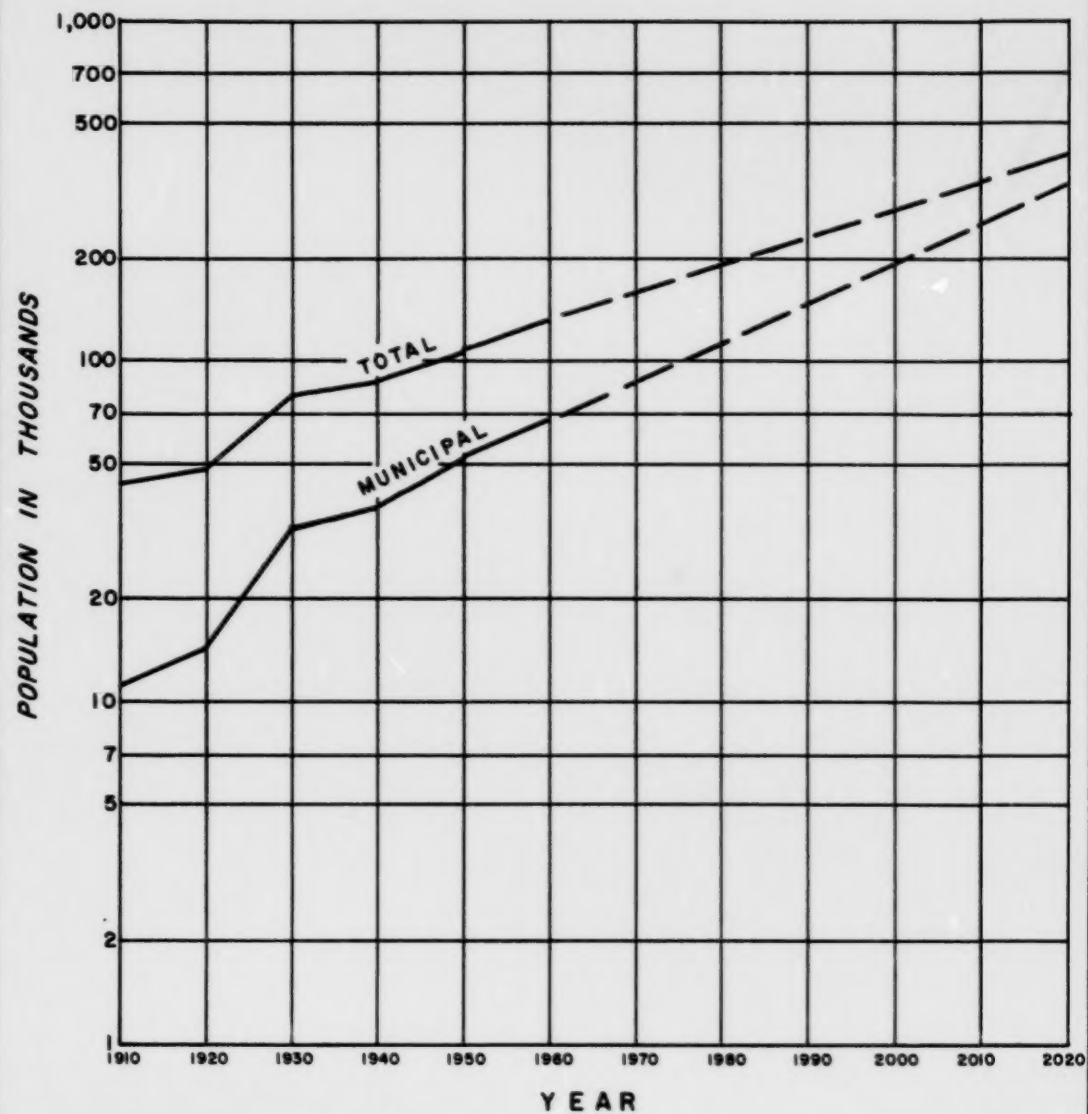


ARKANSAS-RED RIVER BASINS
WATER QUALITY CONSERVATION PROJECT-
BENEFITS EVALUATION

POPULATION TRENDS
SHREVEPORT SMSA L-1

DEPARTMENT OF HEALTH, EDUCATION, & WELFARE
PUBLIC HEALTH SERVICE
REGION VII DALLAS, TEXAS

FIGURE V-15



ARKANSAS-RED RIVER BASINS
WATER QUALITY CONSERVATION PROJECT-
BENEFITS EVALUATION

POPULATION TRENDS
MONROE SMSA L-3

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PUBLIC HEALTH SERVICE
REGION VII DALLAS, TEXAS

FIGURE V-16

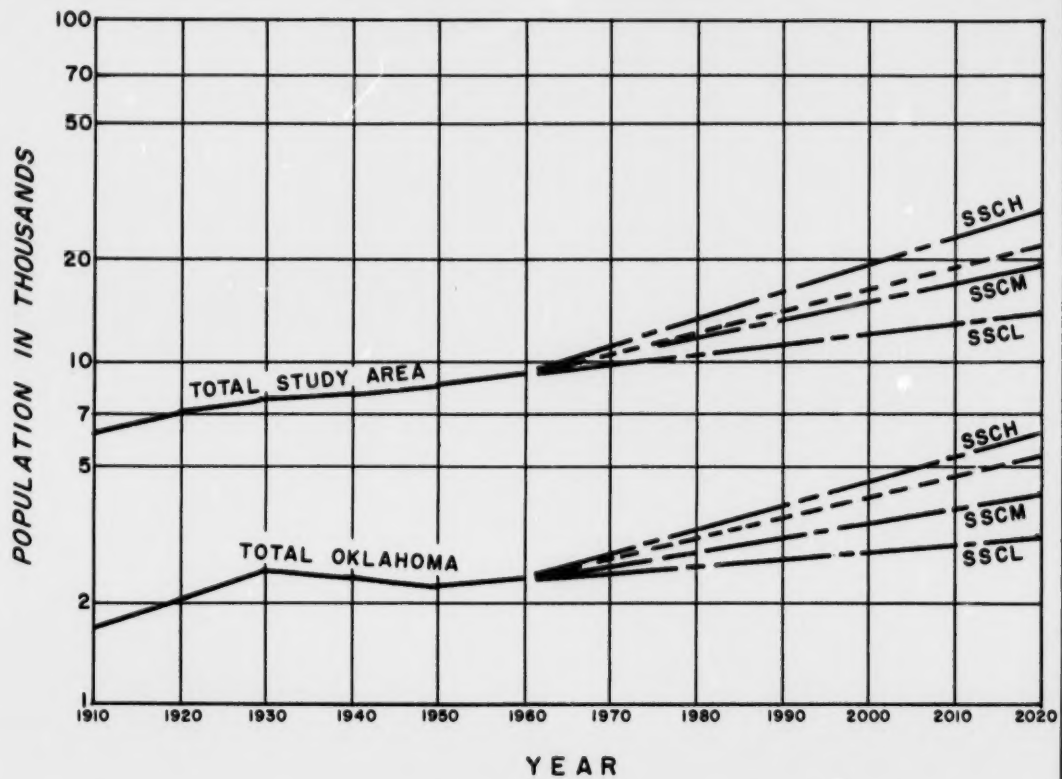
Table V-9

Population Distribution by Subarea Type

Subarea Type	No. of Subareas	Population in Millions					
		1910		1960		2020 (Proj.)	
		Number	% of Total	Number	% of Total	Number	% of Total
SMSA	12	1.30	21	4.58	49	17.21	70
Pop. Center	30	2.07	34	2.38	26	3.93	16
Rural	40	2.76	45	2.37	25	3.32	14

As a check of methods employed to allocate study area projections to subareas, comparisons are drawn between the study area projections and those prepared for a portion of the region. Since the only State entirely within study area boundaries is Oklahoma, it is selected as the component for comparison. Projection ranges (Migration Assumption No. 2) prepared for the Senate Select Committee on Water Resources ^{34/} on the State of Oklahoma and the upper and lower ANR drainage basins (adjusted to coincide with the study area) are compared to projections made for this report in Figure V-17. It will be noted that in both instances projections for this study fall approximately half way between the high and medium SSC projections.

An additional comparison is presented in Figure V-18 which depicts the relationship between total and SMSA projections for the



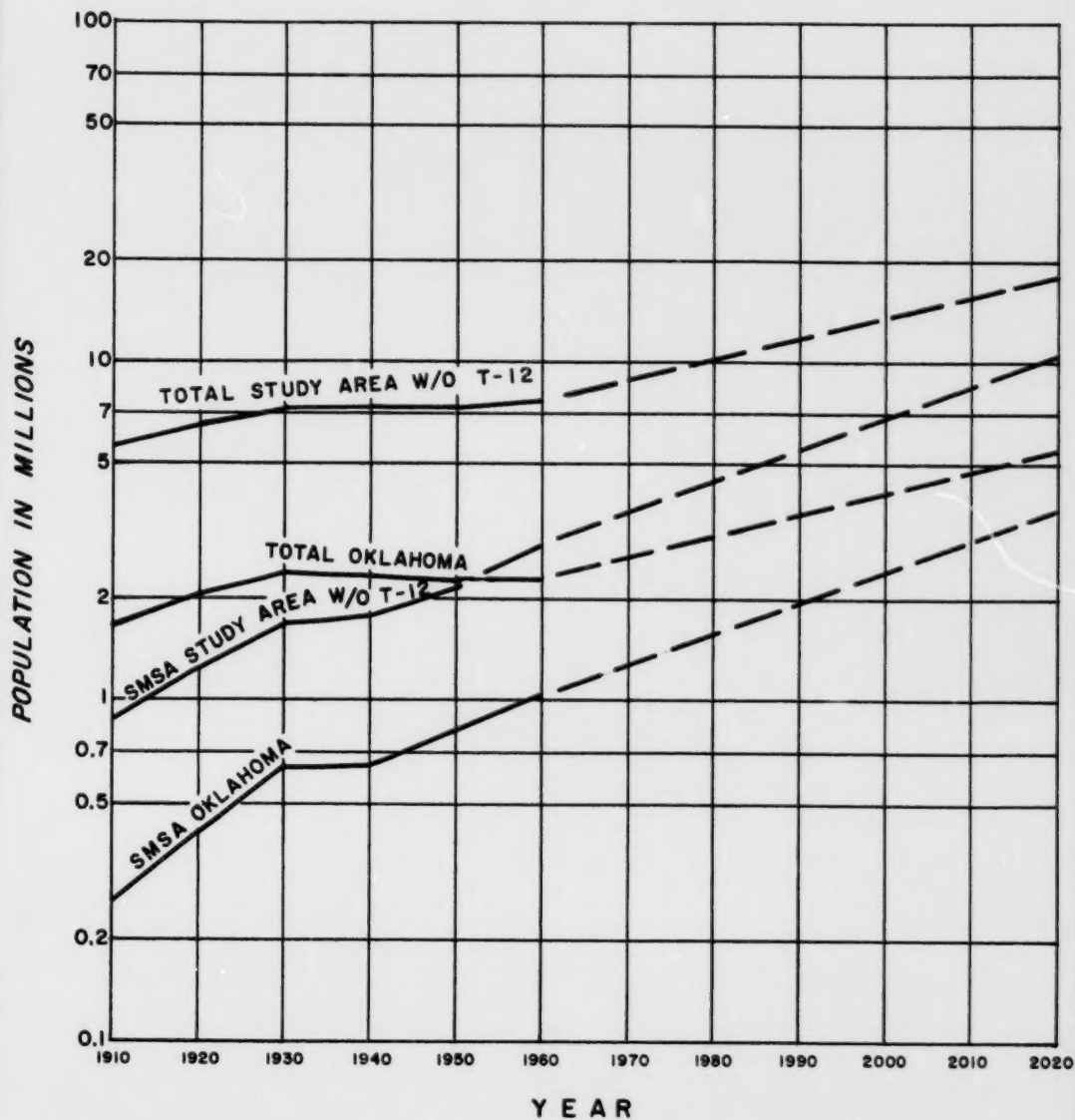
LEGEND:

SSCH - SENATE SELECT COMMITTEE HIGH
 SSCM - SENATE SELECT COMMITTEE MEDIUM
 SSCL - SENATE SELECT COMMITTEE LOW

ARKANSAS-RED RIVER BASINS
 WATER QUALITY CONSERVATION PROJECT -
 BENEFITS EVALUATION
POPULATION TRENDS
 COMPARISON-SENATE SELECT
 COMMITTEE

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 REGION VII DALLAS, TEXAS

FIGURE V-17



ARKANSAS-RED RIVER BASINS
WATER QUALITY CONSERVATION PROJECT-
BENEFITS EVALUATION

**POPULATION TRENDS
STUDY AREA AND OKLAHOMA**

DEPARTMENT OF HEALTH, EDUCATION, & WELFARE
PUBLIC HEALTH SERVICE

REGION VII

DALLAS, TEXAS

FIGURE V-18

study area and the total of individual projections made for Oklahoma subareas. To avoid unrealistic skewing of the study area trends and projections, Subarea T-12 (Dallas - Fort Worth) is excluded from the totals. (It contains 7 percent of the study area 1910 population, 18 percent of the 1960 population, and 26 percent of the projected 2020 population.) In these comparisons, both historic and projected growth rates are almost synonymous.

Table V-10

Sularez Population Data

State Sub- area	Reference City	Type	Population - Historic and Projected					
			Compo- nent	1910	1960	2020		
Colorado	Pueblo- Colo. Sps.	SMSA	Total	95,544	262,449	1,350,000		
			Mun.	72,955	188,791	1,265,000		
	C-2	Lamar	Rural	Total	37,353	40,795	45,000	
				Mun.	5,966	23,475	32,000	
	C-3	Canon City	Rural	Total	68,513	49,084	53,000	
				Mun.	40,628	34,900	40,000	
	C-4	Trinidad	Rural	Total	60,400	55,508	51,000	
				Mun.	27,248	32,943	35,000	
	Subtotal			261,810	407,836	1,499,000		
	Mun.			146,797	280,109	1,372,000		
New Mex.	NM-1	Raton	Rural	Total	52,001	43,302	50,000	
				Mun.	12,810	26,261	38,000	
	NM-2	Clovis	Pop. Center	Total	37,759	52,912	80,000	
				Mun.	6,751	38,606	67,000	
	Subtotal			89,760	96,214	130,000		
	Mun.			19,561	64,867	105,000		
	Kansas	K-1	Garden City	Rural	Total	33,456	69,536	184,000
					Mun.	8,675	48,818	167,000
		K-2	Larned	Rural	Total	22,568	21,884	25,000
					Mun.	5,337	12,238	18,000
K-3		Dodge City	Rural	Total	17,444	28,433	56,000	
				Mun.	5,595	18,767	49,000	
K-4		Medicine Lodge	Rural	Total	22,345	20,885	24,000	
				Mun.	7,608	13,949	19,000	
K-5		Pratt	Rural	Total	51,979	43,226	47,000	
				Mun.	19,636	29,746	38,000	

Table V-10 (Continued)

State Sub- area	Reference City	Type	Population - Historic and Projected			
			Compo- nent	1910	1960	2020
K-6	Great Bend	Pop. Center	Total	17,876	32,368	78,000
			Mun.	8,585	25,367	72,000
K-7	Newton	Rural	Total	73,580	72,970	102,000
			Mun.	30,488	49,437	79,000
K-8	Wichita	SMSA	Total	165,797	478,542	1,775,000
			Mun.	100,155	378,680	1,645,000
K-9	Wellington	Rural	Total	57,076	44,815	57,000
			Mun.	23,695	27,859	44,000
K-10	Eureka	Rural	Total	57,541	33,570	36,000
			Mun.	16,907	18,372	26,000
K-11	Emporia	Rural	Total	190,371	138,739	168,000
			Mun.	92,431	92,161	135,000
K-12	Coffeyville	Pop. Center	Total	49,474	45,007	55,000
			Mun.	33,192	35,500	45,000
K-13	Pittsburg	Pop. Center	Total	51,178	37,032	45,000
			Mun.	25,718	26,975	35,000
			Subtotal	810,685	1,067,007	2,652,000
			Mun.	378,022	777,869	2,372,000
Oklahoma						
O-1	Guymon	Rural	Total	40,622	31,479	39,000
			Mun.	7,400	18,884	30,000
O-2a	Woodward	Rural	Total	64,059	37,487	44,000
			Mun.	13,256	21,419	33,000
O-2b	Clinton	Rural	Total	136,128	91,587	102,000
			Mun.	33,745	58,681	79,000
O-3	Alva	Rural	Total	69,713	36,325	38,000
			Mun.	17,994	20,258	27,000

Table V-10 (Continued)

State Sub- area	Reference City	Type	Population - Historic and Projected			
			Component	1910	1960	2020
0-4	Enid	Pop.	Total	33,050	52,975	96,000
		Center	Mun.	16,026	42,316	85,000
0-5	Ponca City	Pop.	Total	26,999	51,042	85,000
		Center	Mun.	11,083	40,174	76,000
0-6	Tulsa	SMSA	Total	98,803	461,321	1,600,000
			Mun.	48,772	365,120	1,530,000
0-7	Stillwater	Pop.	Total	141,356	113,571	150,000
		Center	Mun.	43,012	75,184	123,000
0-8	Oklahoma City	SMSA	Total	127,576	511,833	1,820,000
			Mun.	82,655	478,770	1,800,000
0-9	Duncan	Pop.	Total	143,194	147,853	190,000
		Center	Mun.	44,207	92,128	151,000
0-10	Lawton	SMSA	Total	34,317	90,803	287,000
			Mun.	9,993	65,756	262,000
0-11	Altus	Pop.	Total	23,737	27,736	49,000
		Center	Mun.	7,375	24,137	45,000
0-12	Frederick	Rural	Total	49,119	36,139	42,000
			Mun.	16,459	21,598	31,000
0-13	Ardmore	Pop.	Total	25,358	39,044	68,000
		Center	Mun.	8,996	25,051	65,000
0-14	Shawnee	Pop.	Total	168,703	142,408	195,000
		Center	Mun.	45,987	88,315	155,000
0-15	Muskogee	Pop.	Total	73,858	98,811	140,000
		Center	Mun.	37,654	70,627	120,000
0-16	Claremore	Rural	Total	85,045	83,511	130,000
			Mun.	24,812	41,146	97,000
0-17	Miami	Rural	Total	54,495	72,373	84,000
			Mun.	11,028	31,780	54,000

Table V-10 (Continued)

State Sub- area	Reference City	Type	Population - Historic and Projected			
			Compo- nent	1910	1960	2020
O-18	McAlester	Pop. Center	Total	47,650	34,360	54,000
			Mun.	23,640	24,943	47,000
O-19a	Poteau	Rural	Total	84,328	63,966	70,000
			Mun.	17,925	25,596	43,000
O-19b	Hugo	Rural	Total	52,661	50,576	75,000
			Mun.	11,138	20,318	49,000
O-20	Durant	Rural	Total	72,015	50,384	88,000
			Mun.	17,944	24,851	68,000
			Subtotal	1,652,786	2,328,184	5,436,000
			Mun.	551,101	1,677,022	4,963,000
Texas						
T-1	Dalhart	Rural	Total	10,585	43,367	150,000
			Mun.	3,100	31,719	140,000
T-2	Amarillo	SMSA	Total	15,736	149,493	1,050,000
			Mun.	11,357	143,836	1,045,000
T-3	Pampa- Borger	Pop. Center	Total	6,424	73,735	201,000
			Mun.	1,154	62,643	192,000
T-4a	Canadian	Rural	Total	6,754	7,666	9,000
			Mun.	1,647	5,264	7,000
T-4b	Childress	Rural	Total	39,074	39,958	38,000
			Mun.	8,768	24,086	27,000
T-5	Hereford	Rural	Total	15,997	54,669	165,000
			Mun.	4,380	26,629	125,000
T-6	Plainview	Pop. Center	Total	7,566	36,798	104,000
			Mun.	2,829	25,486	90,000
T-7	Vernon	Rural	Total	84,221	72,536	73,000
			Mun.	16,922	43,662	53,000

Table V-10 (Continued)

State Sub- area	Reference City	Type	Population - Historic and Projected			
			Compo- nent	1910	1960	2020
T-8	Wichita Falls	SMSA	Total	16,094	123,528	440,000
			Mun.	9,443	117,399	436,000
T-9	Graham	Rural	Total	49,042	39,133	60,000
			Mun.	8,290	25,384	50,000
T-10	Weatherford	Rural	Total	77,904	54,785	84,000
			Mun.	13,944	28,942	64,000
T-11	Sherman	Pop. Center	Total	92,599	95,603	218,000
			Mun.	41,157	71,236	200,000
T-12	Dallas- Fort Worth	SMSA	Total	412,688	1,656,816	6,425,000
			Mun.	218,224	1,556,863	6,365,000
T-13	Paris	Pop. Center	Total	105,911	63,974	150,000
			Mun.	25,257	38,715	133,000
T-14	Greenville	Pop. Center	Total	122,549	93,797	160,000
			Mun.	33,371	62,875	137,000
T-15	Mineola	Rural	Total	55,855	39,737	45,000
			Mun.	5,674	16,309	28,000
T-16	Mount Pleasant	Rural	Total	74,307	57,993	74,000
			Mun.	8,532	28,625	52,000
T-17	Texarkana	Pop. Center	Total	62,414	83,467	132,000
			Mun.	12,111	50,726	107,000
T-18	Marshall	Pop. Center	Total	81,815	142,872	255,000
			Mun.	20,717	98,374	220,000
T-19	Henderson	Pop. Center	Total	47,370	53,291	75,000
			Mun.	-----	21,012	53,000
Subtotal				1,384,905	2,983,218	9,908,000
			Mun.	446,877	2,479,785	9,524,000

Table V-10 (Continued)

State Sub- area	Reference City	Type	Population - Historic and Projected			
			Compo- nent	1910	1960	2020
Missouri						
M-1	Joplin	Pop.	Total	116,809	108,956	130,000
		Center	Mun.	72,796	78,942	100,000
M-2	Aurora	Rural	Total	107,910	80,845	97,000
			Mun.	27,302	33,878	67,000
			Subtotal	224,719	189,801	227,000
			Mun.	100,098	112,820	167,000
Arkansas						
A-1	Fayette- ville	Pop.	Total	67,278	92,069	134,000
		Center	Mun.	17,408	50,439	104,000
A-2	Harrison	Rural	Total	72,640	52,452	56,000
			Mun.	9,710	15,237	30,000
A-3	Van Buren	Rural	Total	237,031	161,180	232,000
			Mun.	38,202	67,700	162,000
A-4	Ft. Smith	SMSA	Total	52,278	66,685	160,000
			Mun.	30,918	58,212	152,000
A-5	Benton	Rural	Total	85,036	89,110	122,000
			Mun.	15,292	39,450	87,000
A-6	Hot Springs	Pop.	Total	27,271	46,697	94,000
		Center	Mun.	14,434	31,741	81,000
A-7	Little Rock	SMSA	Total	139,485	324,353	850,000
			Mun.	72,980	234,174	770,000
A-8	Stuttgart	Pop.	Total	106,420	108,493	133,000
		Center	Mun.	21,238	49,381	91,000
A-9	Texarkana	Pop.	Total	121,257	100,486	113,000
		Center	Mun.	27,639	52,594	80,000
A-10	Magnolia	Rural	Total	43,164	37,100	52,000
			Mun.	6,099	18,210	38,000

Table V-10 (Continued)

State Sub- area	Reference City	Type	Population - Historic and Projected			
			Compo- nent	1910	1960	2020
A-11	El Dorado	Pop. Center	Total Mun.	52,497 13,217	81,159 50,216	160,000 135,000
A-12	Warren	Rural	Total Mun.	59,939 8,492	45,780 18,448	58,000 39,000
A-13	Crossett	Rural	Total Mun.	99,607 18,778	93,640 39,919	130,000 96,000
			Subtotal Mun.	1,163,903 294,407	1,299,204 725,721	2,294,000 1,865,000
Louisiana						
L-1	Shreveport	SMSA	Total Mun.	99,124 33,410	321,182 238,962	1,035,000 975,000
L-2	Ruston	Rural	Total Mun.	190,981 25,315	183,725 74,773	280,000 200,000
L-3	Monroe	SMSA	Total Mun.	44,616 13,664	115,372 84,838	422,000 377,000
L-4	Tallulah	Pop. Center	Total Mun.	132,175 15,856	176,256 65,998	215,000 135,000
L-5	Natchitoches	Pop. Center	Total Mun.	36,455 3,634	35,653 16,006	57,000 43,000
L-6	Alexandria	Pop. Center	Total Mun.	44,545 15,479	111,351 66,531	315,000 280,000
			Subtotal Mun.	547,896 107,358	963,539 547,713	2,324,000 2,010,000
			Grand Total Mun.	6,136,464 2,044,221	9,335,003 6,665,901	24,470,000 22,378,000

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VI. WATER REQUIREMENTS

Past and Present Water Use

Water used by human beings for drinking and other domestic purposes is conceded to be the most essential use of water. Such water is generally given the primary procurement rights and afforded the highest degree of quality protection, but other beneficial uses may have water quality criteria that are far more stringent in certain aspects than waters used for drinking. The following discussion examines three such uses from the standpoint of quantity and quality requirements as related to the Ark-Rad study area.

Municipal

Quantity

Municipal water withdrawals throughout the Nation in 1960 amounted to about 8 percent of the total water withdrawn.^{1/} Though small in relation to industrial and agricultural water needs, municipal requirements are by far the most variable in both locale and type of use.

Included in municipal water uses are demands exerted for lawn sprinkling, car washing, street washing, fire fighting, ice making, air conditioning, food preparation, recreation, manufacturing (cooling and process water), waste conveyance, and countless others. As further pointed out in a succeeding section of this chapter, overall

unit municipal water demand is best expressed in terms of gallons per capita per day (gpcd). This rate of use includes not only water used for residential and public purposes, but that supplied to light industrial and commercial installations directly related to the increasing demands for goods and services by the local population.

Based on weighted average (by population served) data from 27 of the major cities in the study area, mean annual unit municipal water demand increased from 115 gpcd to about 125 gpcd from 1950 through 1959. Though fluctuations occurred through the 10 year period, these trends give definite indications of increasing unit demands. Total municipal water use in the study area in 1960 averaged almost one billion gallons per day. This is about 3 percent of the Nation's estimated total municipal water demand 1 2 3. Tabular data on quantity and quality of individual study area public water supplies are presented in Appendix - Exhibit B.

Quality

The quality of water needed for municipal purposes does not follow a particular set of standards since it serves so many masters. However, water used for domestic consumption is generally given primary consideration and quality recommendations for municipal supplies are usually governed by this use. As a result, high quality water is sometimes used where it is not needed. In other instances, water of much better quality than that recommended for domestic purposes is needed but is unavailable from public systems, and therefore further treatment is necessary.

The most widely accepted municipal water quality standards are those published by the U.S. Public Health Service and adopted by the American Water Works Association for drinking water. ^{4/} The Public Health Service Drinking Water Standards, first promulgated in 1894 as part of the Interstate Quarantine Regulations for prevention of interstate spread of disease, underwent the latest revision in 1962. First regulations, confined to bacteriological quality, were modified in 1925 to include limits for chemical constituents. Limitations in the latest standards include recommended permissible limits for chemicals that are generally nontoxic but have adverse qualities pertaining to color, odor, or taste. Listed are such constituents as copper, iron, chloride, sulfate, arsenic, nitrate, and total dissolved solids. Supplies containing these chemical substances in excesses of the recommended limits should not be used when "other more suitable supplies are/or can be made available."

The suggested limit for the chloride ion concentration in the Public Health Service Standards is 250 ppm. This standard is based on palatability, rather than health, and other agencies or countries have suggested levels from 10 to 500 ppm. ^{5/} Taste have disclosed that some individuals notice chloride salts (sodium chloride in particular) in water with concentrations of 100 ppm; however, the taste becomes perceptible for the average individual when the salt

is present in amounts greater than 200 ppm.^{5/} Although adverse physiological effects may not occur except at high concentrations of chlorides (it is reported, up to 4,000 ppm has no effect on the health of normal persons), lower levels may be injurious to some people suffering from diseases of the heart or kidney.^{6/}

Since chloride salts commonly enter solution in the waters of the Ark-Rad basins as sodium chloride, significant quantities of sodium are also present in these waters.* Sodium is reported harmful in excessive quantities to persons suffering from cardiac, renal, and circulatory diseases. It has been reported that drinking water of good quality may contain up to 115 ppm of sodium, but a limit of 10 ppm is usually recommended as desirable.^{5/}

Much of the waters delivered to consumers through public systems is used for other than domestic purposes, and adverse effects of high chloride concentrations on these uses are also of importance. Many portions of a subsequent discussion on industrial water quality requirements are also applicable to municipal supplies, since in many instances water from the municipal system satisfies much of the industrial demands. Some extent of myriad problems created by high chloride concentrations in municipal water supplies is illustrated by experiences in Dallas, Texas ^{7/} in the mid 1950's when chlorides built up during an extended drought.

* When associated with the chloride ion (NaCl), sodium is present in the ratio of .65 ppm sodium to 1 ppm chloride.

Dallas has a few standby deep wells, but water supply is normally obtained from surface reservoirs. At the beginning of the 1952 through 1956 drought, the city had only one major surface reservoir, Lake Dallas, on a tributary of the Trinity River. As the drought progressed, this source diminished rapidly through use and evaporation. Oilfield brines and concentration of dissolved solids caused by evapotranspiration raised sodium chloride levels (normally in the 60 to 120 ppm range) 10-fold. Extreme shortages prompted installation of emergency pumping facilities on the Red River in early 1954. Through 11 miles of 48" pipeline, salty Red River water was transported over the drainage divide into the Lake Dallas watershed. Although diversion from the Red averaged less than 10 percent of the total municipal supply, daily analysis showed sodium chloride concentrations exceeding 1,400 ppm (850 ppm chlorides) before the drought broke in April 1957. Finished water hardness during this critical period was approximately 500 ppm.

Although assessment of losses directly attributable to high chloride concentration was not attempted, a number of significant problems developed for Dallas residents using municipal water. Evaporative coolers, cooling towers, automobile radiators, and bimetallic plumbing fixtures corroded rapidly. It was not uncommon to repair items damaged by these corrosive tendencies twice in a single year. Lawns and shrubs irrigated with city water died or were severely stunted. Dietary adjustments for low salt intake patients were necessary.

In response to popular demand, the city maintained free watering points at their wells to supply residents with drinking water. Dallas wells, in the Trinity Sands, are at a depth of 2,000', contain NaCl of 200 ppm and have temperatures varying from 110 to 125°F. Other residents purchased bottled water or soft drinks in preference to drinking tap water. Industries normally using Dallas city water supply employed various measures of expediency. Some transferred critical process operations to plants in other cities. Others installed expensive demineralizing equipment. A few hauled water in tank trucks from "fresh" city lakes or other sources.

These problems vividly illustrate why cities have not considered saline streams (see Figure III-2) of the Ark-Red basins as a potential source of supply. Even the main stems are not used for municipal supply (though adequate quantities are available) except in two noteworthy instances (Table B-1, Appendix - Exhibit B). Denison, Texas, periodically uses the Red River to supplement limited yields of their basic sources of water supply. Bossier City, Louisiana, is constructing an off-channel storage reservoir with capacity sufficient to permit bypassing river water during low flow periods when quality is poorest.

Industrial

Quantity

A large portion of the water currently used in the study area is directed toward satisfying the needs of industry. Some industrial demand is directly related to local population in the form of water used by countless small manufacturing and service industries closely associated with municipal growth. This portion of the total industrial demand is included in municipal water demands as discussed in the preceding section.

The largest portion of the industrial demand, however, is reflected in the needs of a few large water using industries not directly related to population. The size and location of these industries is determined more by such factors as: access to raw materials, access to market, water supply, waste disposal, and economies of scale (plant size). These nonpopulation oriented industries referred to in this report as principal water using industries are:

Thermal Power Generation

Petroleum Refining

Chemical (Petrochemical)

Natural Gas Processing

Pulp and Paper

Primary Metals

(a) Iron and Steel

(b) Aluminum

Food and Kindred

About 2 percent of the 12 trillion gallons of water used by all the Nation's principal water using industries (exclusive of thermal power generation) in 1960 was attributed to study area production.^{8/} Since study area production by these industries is much greater than two percent of the national production (see Chapter V), industrial water conservation measures are undoubtedly common practice in the study area. This fact is illustrated by data collected for the 1954 Census of Manufactures^{9/} which shows actual industrial water intake to be 54 percent to the theoretical total requirement (if no recirculation had been practiced) in the Nation as a whole; whereas, in the AWR region, intake water was only 16 percent of the theoretical demand. Greater detail on industrial water use is presented in Exhibit C, appended to this report.

Quality

Many industrial processes cannot use, without further treatment, water considered acceptable for domestic purposes. For instance, water with over 75 ppm chloride concentration is reportedly effective in promoting corrosion of certain metal parts used in paper manufacturing; special chemical processes utilizing water as a conveying medium or as part of the product require water of near distilled quality; and carbon black industries using water for pelleting (packaging) require water with very low dissolved mineral content since residue remains in the product as an impurity.^{10/}

One of the most significant quality factors to large industrial water users is the concentration of total dissolved solids, since it usually governs the permissible number of cycles and the frequency of blowdown in the recirculation of cooling water. If the quality of water is essentially constant and proper material used in construction of the cooling system, however, recirculation even at concentrations approaching that of sea water have been found to be economical (see Appendix - Exhibit F). On the other hand, some industrial processes are adversely effected by waters of less than 100 ppm concentration, i.e., confectionary and rayon industries,^{5/} particularly if specific ions obnoxious to the process are among the dissolved solids. Since a significant portion of the total dissolved solids concentrations in waters of the Arkansas and Red Rivers are attributed to chloride salts, an examination of quality limitation of waters for industrial purposes due to chloride concentration is in order.

The presence of chlorides in industrial waters is a factor of importance to all of the principal water using industries. The level of concentration, however, presents more problems for some than others. Chief objections to high chloride concentrations in industrial waters stems from the characteristic of chlorides to accelerate corrosion in pipes, boilers, and other fixtures. Chloride concentrations as low as 20 ppm have been reported to be corrosive.^{5/} Other objections involve impartation of tastes to products because of chlorides in process waters.

While the chloride concentrations at which water ceases to be useful are not available for all industries studied, Table VI-1 lists the limits suggested for some industries by experts in the field.

Table VI-1

Recommended Threshold Concentrations in ppm ^{5/}

<u>Industry</u>	<u>Chlo- rides</u>	<u>CaCl₂</u>	<u>MgCl₂</u>	<u>NaCl</u>	<u>Total Dissolved Solids</u>
Paper Making:					
Groundwood Pulp	75				
Soda Pulp	75				
Kraft Pulp	200				
Steel Manufacturing	175				
Textile Processes	100				
Sugar Making	20				
Carbonated Beverages	250				
Food Equipment Washing	250				
Brewing		100-200	100-200	275 - 500	
Ice Manufacture		300	171-300	300	
Food Canning and Freezing				1,000-1,500	
Plastics, Clear Uncolored					200
Boiler Feed Water					50-500
[with pressure (PSI) ranging from over 400 PSI to 150 PSI]					

Average stream water qualities presently available to industry in the study area are given at various stream locations on Figure VII-2 and later in Chapter VIII.

Irrigation

Quantity

Water utilized for the irrigation of crops presently is the largest single water use in the study area. In 1959 the study area acreage accounted for 13.4 percent of the estimated 33.2 million acres irrigated in the Nation. ^{11 12/} Area water requirements per acre range from 17 to 25 inches, depending on the location and type of crop irrigated. ^{13/} Of the total 1959 estimated irrigation water use of 8 million acre-feet, approximately 83 percent was supplied by ground water pumpage.

Quality

Water quality is an important factor in evaluating its usefulness for irrigation. There are, however, many aspects involved in evaluating the effects water of a given quality will have on plant growth. In general, good soil drainage may be a more important factor in crop growth than the quality of water. Even when excellent waters are used, poorly drained land may sometimes go out of production; while saline waters, on the other hand, may sometimes be used to irrigate tolerant crops when soil texture and structure permits sufficient leaching of the root zone.

Three criteria commonly used in establishing general suitability of waters to be used for irrigation of crops are:

1. Trace elements - Expressed as concentration of toxic ions.
2. Major cations and/or anions - Expressed as ionic concentration or the ratio of one ion to others.
3. Salinity - Expressed as total concentration of dissolved salts or the ability of water to conduct electric current (mhos per centimeter @ $25^{\circ}\text{C} \times 10^6$).

Probably the most notorious example of a toxic trace element employed to classify irrigation water from a quality standpoint is boron. Although boron is essential for plant growth, the requirements are very small and the element may become toxic to many plants when concentrations above 1 or 2 ppm are reached. 5/

Most of the major dissolved ionic constituents are essential nutrients for plant growth, but some are deleterious to sensitive plants or specific soils. The most common ionic measure of the suitability of a water for irrigation is the ratio of the sodium ion to the remaining cations. If the combining weight (equivalent weights per million - epm) of sodium exceeds that of calcium and magnesium, unfavorable soil conditions may develop. This is particularly true in clayey soils where sodium ions tend to deflocculate the clay fraction and hinder water movement to the root zone. In addition to its effect on soil structure, sodium has a direct toxic effect on some plants as do other ions, such as chloride and sulfate.

Excessive chlorides and sulfates often will cause tip burning of the leaves, and in some cases may be responsible for defoliation. Generally, for most crops, chlorides are considered more harmful than sulfates of equal concentrations, but recommended limits are approximately the same in terms of combining weights (>10 ppm).

All ionized constituents contribute to the total osmotic effect. Osmotic pressures, directly proportional to concentration of salt solutions, may be so high that plant root experience difficulty in absorbing sufficient moisture for optimum growth. Since the ability of plants to extract adequate moisture differs, crops may be classified by salinity sensitivity. Table VI-2 classifies some crops of importance in the study area.

Table VI-2

Relative Tolerance of Crops to Salinity
In Saturated Soil Extract*

High ($EC \times 10^3 = 12$ to 10)	Medium ($EC \times 10^3 = 10$ to 4)	Low ($EC \times 10^3 = 4$ to 3)
<u>Vegetable Crops</u>		
Beets	Most vegetables	Radishes
Asparagus		Celery
Spinach		Beans
<u>Forage Crops</u>		
Bermuda grass	Native grasses	Clovers
Alkali and salt grasses	Hay	
<u>Field Crops</u>		
Barley	Corn	Field beans
Sugar beets	Sorghum	
Cotton	Most small grains	

*Adapted from U. S. Department of Agriculture Handbook #60.

No exact limit can be set for the maximum permissible salt content of irrigation water, since such limitations depend greatly on the kind of salts in solution, soil type, subsoil drainage characteristics, crop tolerance, and farm management practices. In general, however, dissolved solids concentrations in soil solutions are from 5 to 10 times higher than those of the irrigation water. In most cases, the total dissolved solids concentration for irrigation waters of acceptable quality, therefore, will range between 100 and 2,000 ppm. ^{14/} These concentrations are equivalent in most natural waters to electrical conductivity (EC) readings of 160 to 2,800 micromhos.

A general classification of irrigation waters assuming average soil types, cropping patterns, and farm management is given according to quality in Table VI-3.

Table VI-3 ^{15/}

Classification of Irrigation Water

Class*	Total Dissolved Solids		Sodium Chlorides (%)	Sulfates (ppm)	Borates (ppm)
	(ppm)	ECx10 ³			
1	<700	<1,000	<60	<178	<480
2	700-2,100	1,000-3,000	60-75	178-355	480-960
3	>2,100	>3,000	>75	>355	>960

* Class 1 - Excellent to good, or suitable for most plants under most conditions.

Class 2 - Good to injurious, harmful to some plants under certain conditions of soil, climate, and practice.

Class 3 - Injurious to unsatisfactory, unsuitable under most conditions.

Table VI-4 classifies waters of the Arkansas and Red Rivers and their tributaries according to irrigation suitability. The sampling stations listed are those chosen by the Public Health Service to delineate and evaluate the natural salt source areas described in Chapter III of this report. Stations located above sources of natural pollution are indicated by an #, the remainder are in stream reaches to be benefited by the Ark-Red project. All classifications are based on averages of analyses conducted upon weekly grab samples taken over 1½ years of operation of the quality network.

These data show boron concentration is practically insignificant in waters of the Arkansas and Red Rivers. Under percent sodium concentration, Class 1 water quality is exceeded at 31 percent of the stations, most of which are in stream reaches to be benefited by the Ark-Red project. Water of Class 1 sulfate quality exists at 90 percent of the sampling stations, indicating sulfate concentrations are almost insignificant in the Arkansas River basin from an irrigation suitability standpoint. Concentrations in the upper reaches of the Red River basin, however, are much more severe, primarily due to drainage over widespread gypsum outcrops.

Of the five quality measures listed in Table VI-4, the two characteristics most consistently in the poor water range are chlorides and electrical conductance, or total dissolved solids. Since

Table VI-4

VI-16

Irrigation Water Quality Classification (Irrigation Season*)

State	River Basin	Station Number	Station Description	Quality Criteria				
				E.C. (or TPd)	% Sodium	Chlorides	Sulfates	Boron
Kansas	Arkansas	220#	Arkansas River near Great Bend	2	1	1	2	1
		767	Rattlesnake Creek near Raymond	3	3	3	1	1
		760	Arkansas River below Hutchinson	2	1	3	1	1
		223	Arkansas River at Wichita	2	1	1	1	1
		227	Arkansas River at Arkansas City	2	1	2	1	1
		229#	Walnut River near Winfield	2	1	1	1	1
Oklahoma		764#	Salt Fork of Arkansas near Winchester	2	1	2	3	1
Kansas		232#	Medicine Lodge River near Kiowa	2	1	1	1	1
Oklahoma		235	Salt Fork of Arkansas near Jet	3	3	3	1	1
		236	Salt Fork of Arkansas near Tonkawa	3	1	3	1	1
		238	Arkansas River at Ralston	2	1	2	1	1
		246#	Cimarron River near Mocane	2	1	3	1	1
		862	Cimarron River near Buffalo	3	3	3	1	1
		248	Cimarron River near Waynoka	3	3	3	2	1
		251	Cimarron River near Guthrie	3	2	3	2	1
		253	Cimarron River near Perkins	3	3	3	1	1
		258	Cimarron River near Mannford	3	3	3	1	1
		259	Arkansas River at Tulsa	2	1	3	1	1
		283#	Verdigris River near Inola	1	1	1	1	1
		805	Arkansas River at Webbers Falls	2	1	2	1	1
New Mexico		361#	Canadian River at Logan	3	1	1	1	1
Texas		362#	Canadian River near Amarillo	2	1	1	1	1
		363#	Canadian River near Canadav	2	2	1	1	1
Oklahoma		364#	Canadian River at Bridgeport	2	2	2	1	1
		838#	Canadian River at Purcell	2	1	2	1	1
		366#	Little River near Tecumseh	1	1	1	1	1
		763#	Salt Creek of Little River near DeWright	3	2	3	1	1
		367#	Little River near Sasakwa	3	2	3	1	1
		368#	Canadian River at Calvin	2	1	2	1	1
		762#	N. Canadian River below Lake Overholser	1	1	1	1	1
		387#	N. Canadian River near Oklahoma City	2	1	3	1	1
		388#	N. Canadian River near Wetumka	2	1	3	1	1
		765#	Wewoka Creek near Wetumka	3	2	3	1	1
		390#	Deep Fork near Beggs	1	1	1	1	1
		761#	N. Canadian River near Eufaula	2	1	3	1	1
		392#	Canadian River near Whitefield	2	1	2	1	1
Arkansas		403	Arkansas River at Van Buren	2	1	1	1	1
Texas	Red	478	Prairie Dog Town Fork (Red) near Brice	3	2	3	3	1
		768	Prairie Dog Town Fork (Red) near Estelline	3	3	3	3	1
		750	Prairie Dog Town Fork (Red) near Quanah	3	3	3	3	1
		703#	Salt Fork near Wellington	2	1	2	3	1
Oklahoma		481#	Salt Fork near Mangum	2	1	1	3	1
		483#	North Fork River near Carter	2	1	2	2	1
		754#	Elm Fork at Salton Crossing	3	1	3	3	1
		753	Elm Fork near Carl	3	3	3	3	1
		490	North Fork River near Headrick	3	1	3	2	1
Texas		755	Pease River near Quanah	3	2	3	3	2
		759	Pease River near Vernon	3	1	3	3	2
		497	Red River near Burkburnett	3	2	3	2	1
Oklahoma		500#	Cache Creek near Walters	1	1	1	1	1
Texas		756	South Fork of the Wichita River near Benjamin	3	2	3	3	2
		757	North Fork of the Wichita River near Truscott	3	2	3	3	2
		758	Wichita River near Seymour	3	3	3	3	2
		752	Wichita River below Lake Kemp	3	1	3	2	2
		751#	Beaver Creek near Electra	2	1	3	1	1
		503	Wichita River at Wichita Falls	3	1	3	2	1
Oklahoma		700#	Beaver Creek near Waurika	2	1	1	1	1
Texas		704#	Little Wichita River near Henrietta	1	1	2	1	1
		507	Red River near Terrell	3	1	3	2	1
		508	Red River near Gainesville	3	1	3	2	1
Oklahoma		520#	Washita River near Durwood	2	1	1	1	1
Texas		522	Red River near Colbert	2	1	2	1	1
Oklahoma		526#	Clear Boggy Creek near Caney	1	1	1	1	1
Texas		527	Red River at Arthur City	2	1	2	1	1
Arkansas		529	Red River at Index	2	1	2	1	1

*Average of samples taken during irrigation season - June, July, August, and September.

#Stations which will not be benefited by the Ark-Red Project. Pollution caused chiefly by oilfield brines.

specific conductance is significantly influenced by chlorides in these streams, the chloride ion appears to be the most significant single ionic quality hazard in these waters. With the present quality of water, irrigation is limited to particular stream reaches in the study area. For instance, the Red River is generally considered of unsuitable quality for irrigation, except in the reach below Shreveport. 16/

Projected Unit Water Demands

Municipal

Subarea municipal water requirements projected to the year 2020 are computed by multiplying a unit use factor (gpcd) by the projected municipal population. With future municipal population data having been developed in Chapter V, it remains then to provide appropriate unit use figures expected to prevail in the future.

Gallons per capita per day for the period 1950-60 are calculated from data collected at 44 cities in the study area, (Appendix - Exhibit B). In reviewing these data, a general increase in gpcd is noted from east to west. An abnormally higher rate of water use is also apparent for the year 1956. Gpcd figures are compared with several parameters to determine whether any single factor or combination of factors are significant in causing the varying rate of use. This examination indicates that the rate of water use generally increased as climate approached aridity. Rainfall data, being a readily available climatic indicator, are chosen as the governing

criterion for projection of 2020 use rates. Since municipalities do not all have the same water use characteristics, present "dry year" (1956) rates are normalized to form a base for projecting future dry year unit demands.

By plotting weighted (by population served) gpcd figures from 1950 through 1959, an average increase of 0.62 gpcd/yr. is shown in the study area. Assuming that this average rate will continue, an increase of 37 gpcd can be expected by the year 2020. Thirty-five to forty gpcd is added to the present normalized dry year rates to obtain future design year demand rates varying from 115 to 205 gpcd as presented in Table VI-5 by precipitation belts. The appropriate projected rate multiplied by municipal population provides the sub-area municipal water demands presented in Table VI-7 at the end of this section.

Table VI-5

2020 Municipal Dry Year Unit Water Demands

<u>Annual Precipitation Range (inches)</u>	<u>Unit Demand Range (gpcd)</u>
<10	205-195
10-15	195-185
15-20	185-175
20-25	175-165
25-30	165-155
30-35	155-150
35-40	150-145
40-45	145-135
45-50	135-125
>50	125-115

Industrial

As pointed out in a preceding section of this chapter and Appendix - Exhibit C, significant industrial water demands in the study area are attributed to a few industrial classes, namely:

Thermal Power Generation

Petroleum Refining

Chemical (Petrochemical)

Gas Processing

Pulp and Paper

Primary Metals

(a) Iron and Steel

(b) Aluminum

Food and Kindred

In order to arrive at future water demands for these industries, it is necessary to establish the probable level of production in the year 2020. Size and location of major water using industries is not directly related to local population, since production is predicated upon markets of national, rather than local extent. It is, therefore, necessary to project production for these industries based on the anticipated study area share of projected national production. Since industrial water demands are best expressed in number of gallons per unit of product, unit demands are projected on this basis, rather than on demands per employee. These demands may include either high and/or low quality water.

Sufficient data are not available to project unit demand figures for the natural gas, primary metals, and food and kindred industries. Therefore, regional water requirements are projected for these industries as an increase over present water demand in proportion to expected production increases.

Unit water demands for the remaining industries are as follows:

<u>Industry</u>	<u>Unit Demand</u>
Thermal Electric	0.7 gal./kw.-hr.
Petroleum Refining	1,722 gal./bbl. oil refined
Petrochemical	84,000 gal./ton
Pulp and Paper	35,000 gal./ton pulp

Allocation of production and attendant water demands are affected by analysis of each subarea's relative competitive position within the study area. Individual subarea industrial water requirements are adjusted to take cognizance of expected cooling water reuse necessitated by water availability. Subarea projected water demands are summarized in Table VI-7 at the end of this section.

Irrigation

A third significant water use in the Ark-Red study area is that required for irrigation of agricultural commodities. Always a necessity in arid regions, irrigation to supplement periodically deficient rainfall in the more humid portion of the area is becoming increasingly common.

It is necessary to determine future irrigation demands to establish the ability of anticipated stream discharges to support irrigation projected for individual watersheds. Since requirements in any given location depend not only upon crops grown, but individual farm practices and climatic conditions, generalized unit demands are developed to represent average conditions in each type-of-farming area (Appendix - Exhibit D).

Water requirements for irrigation are generally expressed in terms of acre-inches per acre for the season (usually April through September) or for any month. Seasonal unit demands are projected with the aid of data presented in Senate Select Committee Print No. 12 and water requirement estimates developed by the U.S. Bureau of Reclamation. These demands are prorated by months for purposes of determining the critical month (August) of high water requirement and low streamflow. Unit requirements for the season and August are presented in Table VI-6.

Table VI-6

2020 Unit Irrigation Water Requirements
(Acre-inches Per Acre)

<u>Type-of-Farming Area</u>	<u>Annual</u>	<u>August</u>
1	25	8
2	25	8
3	20	6
4	26	9
5	18	6
6	18	6
7	22	8
8	14	4
9	14	4
10	17	6
11	17	6

Total water demands projected for each type-of-farming area by source (ground and surface) are presented in Table VI-8.

Table VI-7 (Continued)

Sub-area	Municipal	Industrial ^a								Total Projected Requirements	
		O	G	PC	IAS	AL	P.P	F&K	TE	M & I High Quality	Cooling Low Quality
K-11	24	44						2	7	33	44
K-12	8	34						1	2	15	30
K-13	6							1	2	7	2
Sub-total	452	155	5	77				7	115	532	279
O-1	6		2						2	8	2
O-2a	6								2	6	2
O-2b	15		1						5	16	5
O-3	5								2	5	2
O-4	17	13						1	4	23	12
O-5	14	100	2	48				1	4	40	129
O-6	270	116		48					70	297	207
O-7	22	21							7	29	21
O-8	315		1					2	80	318	80
O-9	26	23	2						8	39	30
O-10	47								13	47	13
O-11	8								2	8	2
O-12	6	3							2	7	4
O-13	11	11							3	15	10
O-14	26		1						9	27	9

Table VI-7 (Continued)

Sub- area	Muni- cipal	Industrial*								Total Projected Requirements	
		O	G	PG	Y&S	AL	P&P	P&K	TE	M & I High Quality	Cooling Low Quality
0-15	20	27						1	6	25	29
0-16	16						3		5	19	5
0-17	8								4	8	4
0-18	8								2	8	2
0-19a	7						25		3	32	3
0-19b	8						49		3	57	3
0-20	12								4	12	4
Sub- total	873	324	9	96			77	5	240	1,046	578
T-1	28	106	59					1	7	91	110
T-2	209	79	1	25					46	248	112
T-3	37	30	4	25					9	59	46
T-4a	1								1	1	1
T-4b	5								2	5	2
T-5	25								7	25	7
T-6	18							1	5	19	5
T-7	10								3	10	3
T-8	81	9		14					19	90	33
T-9	9								1	9	3
T-10	12		3						4	13	6

Table VI-7 (Continued)

Sub-area	Municipal	Industrial*								Total Projected Requirements	
		O	G	PC	ISS	AL	P&P	P&K	TE	M & I High Quality	Cooling Low Qual
T-11	35	2	1					1	10	37	12
T-12	1,114	16					1	10	283	1,129	295
T-13	22							19	7	41	7
T-14	24							1	7	25	7
T-15	5								2	5	2
T-16	9	27			33				3	46	26
T-17	17						45		6	62	6
T-18	34	15	2	111			38		11	8	118
T-19	8		4						3	9	6
Sub-Total	1,703	284	74	175	33		74	33	438	2,007	807
M-1	16							1	6	17	6
M-2	9							3	4	12	4
Sub-total	25							4	10	29	10
A-1	15							5	6	21	6
A-2	4								3	4	3
A-3	22						70	5	10	97	10
A-4	24							2	7	26	7
A-5	12					12			5	24	5

Table VI-7 (Continued)

Sub-Area	Municipal	Industrial*								Total Projected Requirements	
		O	G	PC	L&S	AL	P&P	F&A	FE	M & I High Quality	Cooling Low Quality
A-6	10								4	10	4
A-7	96						33	3	37	132	37
A-8	11							1	6	12	6
A-9	12								5	12	5
A-10	6		2	25					2	9	26
A-11	19	142		94			63		7	92	213
A-12	5								3	5	3
A-13	12						23		6	35	6
Sub- Total	248	142	2	119		12	169	17	101	479	531
L-1	146	32	3	143			52	2	46	223	201
L-2	27		1				20		12	48	12
L-3	47		1	150			60		19	128	149
L-4	16		1					2	10	19	10
L-5	6								3	6	3
L-6	35						18	1	14	54	14
Sub- Total	277	32	6	293			150	5	104	478	389
Grand Total	3,875	937	90	760	109	12	470	77	1,079	4,950	2,465

Table VI-7 (Continued)

* INDUSTRIAL CLASSIFICATION TABLE

<u>Symbol</u>	<u>Industry</u>	<u>Included in SIC No.</u>
O	Oil Refining	29
G	Natural Gas	13
PC	Petrochemical	28
I&S	Iron and Steel	3311 and 3312
AL	Aluminum	3334
P&P	Pulp and Paper	26
F&K	Food and Kindred Products	20
TE	Thermoelectric	4911

** Includes water used by the Steel Industry for quenching
(Must be of better quality than average cooling waters).

*** Includes 3 mgd seasonal demand during beet sugar campaign.

Table VL-8

2020 Irrigation Water Requirements
(1,000 Acre-feet)

Type-of-Farming Area	Water Source		Total
	Surface	Ground	
1	1,060	190	1,250
2	120	3,450	3,570
3	30	220	250
4	150	430	580
5	50	20	70
6	70	60	130
7	80	40	120
8	130	30	160
9	270	50	320
10	250	510	760
11	<u>1,220</u>	<u>710</u>	<u>1,930</u>
Total	3,430	5,710	9,140

Plans for Supplying Future Requirements

Water plans for the 82 subareas in the study area are shown in Table VI-9.

The projected 2020 requirement for high quality water suitable for municipal use and/or industrial process use is listed for each subarea from data developed in previous sections. In some subareas, it was not feasible to satisfy two or more localities having large future requirements by a single water plan. In these subareas, needs are divided, and separate requirements and potential sources of supply are presented for each of the projected demand areas.

Total firm yields for each subarea are summarized under Present Sources from ground water and surface water. The itemized breakdown of these data are presented in Table B-1, Appendix - Exhibit B. Due to yield estimates for some municipal supplies and congruity with projected requirements, these data are rounded to the nearest million gallons per day.

Committed Sources are future water supply sources for which municipalities or industries have obligated themselves. They include approved or constructed Federal projects for which future payment contracts have been negotiated, and municipal or State projects for which construction funds have been committed.

In demand areas where firm yields from Present Sources and Committed Sources do not meet or exceed the projected M & I high quality water requirement, Potential Sources are listed to satisfy

the unmet need. These Potential Sources of water supply are presented with and without the proposed Ark-Red quality control project.

The developed water plans with and without the proposed project are based on the following assumptions:

Alternate sources shall require no greater transmission cost than \$0.05 per 1,000 gallons of water.

All Federal reservoir projects, either under construction, authorized, or recommended for construction, will be in place.

Manmade (from oilfields brine) pollution will be reduced by 85 percent. Potential Sources made usable by such quality improvement are considered as alternate sources.

Water downstream from the 15 identified sources (Ark-Red project areas) of natural brine pollution are considered Potential Sources of supply with the project in place pending closer examination to establish quantity and quality suitability.

These assumptions are general and their application is solely to delineate areas where benefits are possible. In the next chapter of this report, a detailed examination of each of the 17 potential benefit areas thus disclosed evaluates the individual applicability of these assumed conditions.

Table VI-9
Water Plans for 2020 Requirements
(mgd)

State - Subarea	M. & I. High Quality Water	Present Sources - Yields	Committed Sources - Yields	Potential Sources	
				Without Project - Yields	With Project - Yields
<u>Colorado</u>					
C-1	331	Surface Water 66		Eagle River 265 Frying Pan Project 63 Other Surface West Slope Waters 9	Eagle River 265 Frying Pan Project 63 Other Surface West Slope Waters 9
C-2	7	Ground Water 29			
C-3	8	Surface Water 11 Ground Water 9			
C-4	11	Surface Water 24 Ground Water 10			
<u>New Mexico</u>					
NM-1	8	Surface Water 8 Ground Water 2			
NM-2	14	Ground Water 14			
<u>Kansas</u>					
K-1	47	Ground Water 25		Ground Water 22	Ground Water 22
K-2	4	Ground Water 6			
K-3	10	Ground Water 4		Ground Water 6	Ground Water 6
K-4	4	Ground Water 8			
K-5	7	Ground Water 17			
K-6	14	Ground Water 16			
K-7	21	Surface Water 18 Ground Water 17		Smoky Hill River 3 Ground Water	Smoky Hill River 3 Ground Water
K-8	357	123	38	196	195
Wichita	258	Ground Water 85	Cheney Reservoir 38	Murdock Reservoir 135 Kaw Reservoir 23	Murdock Reservoir 135 Kaw Reservoir 23
El Dorado	25	Surface Water 6		El Dorado Reservoir 19	El Dorado Reservoir 19
Other Municipalities	74	Ground Water 32 Surface Water 31		Ground Water 42	Ground Water 42
K-9	8	Surface Water 8 Ground Water 3			
K-10	5	Surface Water 3 Ground Water 2		Toronto Reservoir 2 Fall River Reservoir Neosho River & Lake Kahola Ground Water	Toronto Reservoir 2 Fall River Reservoir Neosho River & Lake Kahola Ground Water
K-11	33	Surface Water 24 Ground Water 22		Toronto Reservoir 9 Fall River Reservoir Neosho River & Lake Kahola Ground Water	Toronto Reservoir 9 Fall River Reservoir Neosho River & Lake Kahola Ground Water
K-12	15	Surface Water 12		Verdigris River 3 Big Hill Reservoir Toronto Reservoir Fall River Reservoir Elk City Reservoir	Verdigris River 3 Big Hill Reservoir Toronto Reservoir Fall River Reservoir Elk City Reservoir

Table VI-9 (Continued)
Water Plans for 2020 Requirements
 (mgd)

State - Subarea	M. & I. High Quality Water	Present Sources - Yields		Committed Sources - Yields		Potential Sources			
						Without Project - Yields		With Project - Yields	
K-13	7	Ground Water	6			Ground Water	1	Ground Water	1
<u>Oklahoma</u>									
0-1	7	Ground Water	11						
0-2a	6	Ground Water	12						
0-2b	15	Surface Water	19	Foss Reservoir	10 ^{A/}				
		Ground Water	4						
			15						
0-3	5	Ground Water	12						
0-4	23	Ground Water	14						
						Ground Water	9	Ground Water	9
						Canton Reservoir		Canton Reservoir	
0-5	40	Surface Water	19				21		21
		Ground Water	18			Kaw Reservoir		Kaw Reservoir	
			1			Ground Water		Ground Water	
0-6	301		149	47			105		105
Tulsa	272	Surface Water	132	Oologah Reservoir	47	Oologah Reservoir	93	Keystone Reservoir	93
Bartlesville	27	Surface Water	15			Sand Reservoir	12	Sand Reservoir	12
Other Municipalities	2		14 ^{A/}						
		Ground Water	4						
		Surface Water	10						
0-7	29	Surface Water	27			Surface Water	2	Surface Water	2
		Ground Water	18						
			9						
0-8	318	Surface Water	113	Atoka Reservoir	71	Tuskahoma Reservoir	134	Keystone Reservoir	134
		Ground Water	46	Norman Reservoir	45				
			67		26				
0-9	39		24				15		15
Duncan	18	Surface Water	3			Hennepin Reservoir	15	Red River	15
Other Municipalities	21	Surface Water	23 ^{A/}						
		Ground Water	10						
			13						
0-10	47	Surface Water	11	Cache Cr. Reservoir	9	Waurika Reservoir	27	Red River	27
0-11	8	Surface Water	4			Mountain Park Reservoir	4	North Fork of Red River	4
0-12	7	Surface Water	7						
		Ground Water	2						
			5						
0-13	15	Surface Water	7			Arbuckle Reservoir	8	Lake Texoma	8
		Ground Water	6						
			1						
0-14	27	Surface Water	30						
		Ground Water	17						
			13						
0-15	25	Surface Water	61						
0-16	19	Surface Water	12			Oologah Reservoir	7	Oologah Reservoir	7
0-17	8	Surface Water	10						
		Ground Water	2						
			8						
0-18	8	Surface Water	8						
0-19a	32	Surface Water	6			Brasil Creek Reservoir	26	Arkansas River	26

^{A/} Greater than projected requirement.

Table VI-9 (Continued)
 Water Plans for 2020 Requirements
 (mgd)

State - Subarea	M. & I. High Quality Water	Present Sources - Yields		Committed Sources - Yields		Potential Sources			
						Without Project - Yields		With Project - Yields	
0-19b	57		168						
		Surface Water	166						
		Ground Water	2						
0-20	12	Surface Water	8			Local Surface & Ground Water	4	Local Surface & Ground Water	4
<u>Texas</u>									
T-1	91	Ground Water	20			Ground Water	71	Ground Water	71
T-2	248	Ground Water	75	Sanford Reservoir	32	Ground Water	141	Ground Water	141
						Reservoir on Mustang Creek or Prairie Dog Town Fork Red R.		Reservoir on Mustang Creek or Prairie Dog Town Fork Red R.	
T-3	59	Ground Water	32	Sanford Reservoir	11	Ground Water	16	Ground Water	16
						Reservoir on North Canadian River		Reservoir on North Canadian River	
T-4a	1	Ground Water	1						
T-4b	5		13						
		Surface Water	2						
		Ground Water	11						
T-5	25	Ground Water	21			Ground Water	4	Ground Water	4
T-6	19	Ground Water	15			Ground Water	4	Ground Water	4
T-7	10		17						
		Ground Water	16						
		Surface Water	1						
T-8	90		25	Halsell Reservoir	38	Ringold Reservoir	27	Lake Kemp	27
		Surface Water	23						
		Ground Water	2						
T-9	9		6				3		3
		Surface Water	5			Halsell Reservoir		Halsell Reservoir	
		Ground Water	1			Ground Water		Ground Water	
						Brazos River		Brazos River	
T-10	13		9			Ground Water	4	Ground Water	4
		Surface Water	8						
		Ground Water	1						
T-11	37								
Denison-Sherman	27	Surface Water	8	Lake Texoma	19				
Gainesville	10	Ground Water	3			Aubrey Reservoir	7	Red River	7
T-12	1,129		306						
		Surface Water	251	Iron Bridge	323	Roswell Reservoir	500	Lake Texoma	500
		Ground Water	55	Reservoir	146				
				Cedar Creek	174				
				Reservoir	3				
				Miscellaneous					
T-13	40		10			Sanders Reservoir	30	Sanders Reservoir	30
		Ground Water	4						
		Surface Water	6						
T-14	25	Surface Water	14	Iron Bridge	24 ^{b/}				
				Reservoir					
T-15	5		7						
		Ground Water	5						
		Surface Water	2						
T-16	46		7	Ferrelle Bridge	45 ^{b/}				
		Ground Water	4	Reservoir					
		Surface Water	3						

^{b/}Greater than unsatisfied projected requirements.

Table VI-9 (Continued)
Water Plans for 2020 Requirements
(mgd)

State - Subarea	M. & I. High Quality Water	Present Sources - Yields		Committed Sources - Yields		Potential Sources			
						Without Project - Yields	With Project - Yields		
T-17	62		11		56 ^{S/}				
		Surface Water	7	Barkman Creek	7				
		Ground Water	4	Reservoir	45				
				Lake Texarkana	7				
				Millwood Reservoir	4 ^{S/}				
T-18	83		67			Ferrells Bridge	16	Ferrells Bridge	16
		Surface Water	60			Reservoir		Reservoir	
		Ground Water	7						
T-19	9		5						
		Ground Water				Ground Water	4	Ground Water	4
						Sabine River		Sabine River	
<u>Arkansas</u>									
A-1	21		15			Beaver Reservoir	6	Beaver Reservoir	6
		Surface Water	13						
		Ground Water	2						
A-2	4		4						
		Surface Water	3						
		Ground Water	1						
A-3	97		14						
		Surface Water	7			Local Ground &	83	Local Ground &	83
		Ground Water	7			Surface Water	9	Surface Water	9
						Arkansas River Tribu-	72	Arkansas River	74
						taries Impound-			
						ments			
						Lake Fort Smith	2		
A-4	26		11						
		Surface Water				Lake Fort Smith &	15	Arkansas River	15
						Frog Bayou &			
						Spring Lake			
A-5	24		85						
A-6	10		14						
A-7	132		163						
		Surface Water	104						
		Ground Water	59						
A-8	12		9			Ground Water	3	Ground Water	3
		Surface Water	2						
		Ground Water	7						
A-9	12		9						
		Surface Water	1			Ground Water	3	Ground Water	3
		Ground Water	8			Gillham Reservoir		Gillham Reservoir	
						Millwood Reservoir		Millwood Reservoir	
						Dierks Reservoir		Dierks Reservoir	
						DeQueen Reservoir		DeQueen Reservoir	
						Narrows Reservoir		Narrows Reservoir	
A-10	9		1						
		Ground Water				Little Missouri	8	Little Missouri	8
						River		River	
						Bayou Dorcheat		Bayou Dorcheat	
						Ground Water		Ground Water	
A-11	92		149						
		Surface Water	130						
		Ground Water	19						
A-12	5		3			Ground Water	2	Ground Water	2
A-13	35		31			Ground Water	4	Ground Water	4

^{S/} More if needed.

Table VI-9 (Continued)
 Water Plans for 2020 Requirements
 (mgd)

State - Subarea	M. & I. High Quality Water	Present Sources - Yields		Committed Sources - Yields	Potential Sources		
					Without Project - Yields	With Project -	Yields
<u>Louisiana</u>							
L-1	223	Surface Water	123		Red River off-channel storage	100	Red River 100
		Ground Water	84				
			39				
L-2	48	Ground Water	8		Ground Water	20	Ground Water 20
L-3	128	Surface Water	1,048				
		Ground Water	1,036				
			12				
L-4	6	Ground Water	9				
L-5	6	Ground Water	2	Sibley Lake	8 1/2		
L-6	54	Ground Water	14		Brown & Valentine Reservoirs	40	Red River 40

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VII. BENEFITS OF THE PROJECT

Methods of Evaluation

Benefits attributable to quality control structures proposed for the 15 delineated sources of natural brine pollution are derived from the projected 2020 municipal, industrial, and agricultural water requirements. Different methods are necessary for determining benefits to agricultural water needs than those used for municipal and industrial water needs.

Benefits to municipal and industrial water needs are computed from the cost of obtaining water to satisfy projected demands from a project source or from the alternative source that would most likely be utilized in the absence of the project. Benefits are the difference in the combined costs of storage, transmission, and treatment of water from the most likely alternative source vs. water from the project source.

Benefits to agricultural water needs are computed from the net farm income from agricultural acreages that would irrigate only with waters made usable by the project. For each type-of-farming area where benefits would accrue from water quality improvement, an analysis is made to determine the net return to land risk and management for irrigated and nonirrigated cropping patterns. Projected prices, cost, and yields are used in this analysis.

Municipal and Industrial Benefit Areas

Total benefit of the proposed brine control projects to municipal and industrial water use is the accumulative benefits of 17 subareas having potential future water sources from project reaches of the streams. Assumed conditions used in selection of subarea potential water sources are examined to evaluate actual benefits. Transmission costs from each source is computed and added to the respective cost of storage and treatment, if applicable. The algebraic summation of total cost differential, if positive, is the benefit of the project to the subarea under study, if quantity and quality are adequate.

Quality and quantity of water in the project stream reaches are calculated under projected 2020 conditions with and without the quality control structures. Benefits are limited to high quality municipal and industrial process water requirements. Cooling water requirements may be met with or without the proposed projects at no significant difference in cost.

The 17 potential benefit areas are described in the following paragraphs. The major present and committed water sources are given, along with the selected project and alternate sources, with their respective transmission distances. Presented are the conditions of quality improvement necessary to provide suitable water from project sources.

Additional quality data are given in the succeeding chapter. In the subareas examined no major difference in water treatment cost between the alternate and project source was found, consequently, these costs are not included.

K-8 - Wichita

Subarea K-8 consists of Cowley, Butler, Sedgwick, and Reno Counties in south-central Kansas. The expected 2020 municipal and industrial process water requirement averages 357 mgd. There are four demand centers in this subarea--Wichita has a projected requirement of 258 mgd; the Winfield-Arkansas City area 14 mgd; El Dorado 25 mgd; and Hutchinson 17 mgd.

Wichita is located at the junction of the Arkansas River and the Little Arkansas River and within economic transmission distance of the Cheney Reservoir site on the North Fork of the Ninnescah River, the Murdock Reservoir site on the South Fork of the Ninnescah River, and the Kaw Reservoir site near Ponca City, Oklahoma on the Arkansas River. There is additional ground water along the Arkansas River and the Equus Beds between the Arkansas and Little Arkansas Rivers.

El Dorado and Winfield-Arkansas City are in the Walnut River basin which has four reservoir sites under study by the Corps of Engineers--Towanda, El Dorado, Douglass, and Wingate Reservoirs. Winfield-Arkansas City have additional ground water supply from the Arkansas River Alluvium.

Hutchinson, located on the Arkansas River in Reno County, utilizes ground water as the present source of supply. Ground water can supply Hutchinson's projected 2020 requirements with little additional cost. Other communities in the subarea have adequate yield from present sources or small future requirements which can be met by minor local improvements.

The high quality 2020 water requirements unsatisfied by present or firmly committed sources are: 20 mgd for El Dorado, 14 mgd for Winfield-Arkansas City, and 150 mgd for Wichita. The Kaw Reservoir is the most likely project source. The mean monthly chloride concentration of record (September 1902 to September 1906 and September 1921 to September 1959) at Arkansas City, Kansas is 350 ppm. Complete removal of the salt load from Area XII on Rattlesnake Creek (the only upstream Ark-Red project salt brine area) would only reduce this concentration to about 315 ppm. Removal of 50 percent of the manmade salt load, however, would reduce the chloride concentration to 245 ppm 90 percent of the time and 100 ppm 80 percent of the time in the Kaw Reservoir.

Because of minimal effect of the Ark-Red project on water quality, no benefits are attributable to proposed quality improvement structures.

0-4 - Enid

Subarea 0-4 consists of Garfield County in north-central Oklahoma. The 2020 municipal and industrial process water requirement is 23 mgd. Enid is considered the demand center of this subarea.

Turkey Creek and Skeleton Creek drain Garfield County. The Salt Fork of the Arkansas and the Cimarron River are the closest major streams. Enid presently obtains its water supply from 84 wells yielding 14 mgd.

Canton Reservoir, on the North Canadian River, is submitted as the alternate source to supply the 9 mgd of unsatisfied requirement. Transmission distance is 42 miles.

The minimum distance to the Salt Fork (the closest project source) is 18 miles. However, the minimum monthly flow of the river is not sufficient to develop a dependable 9 mgd yield and use of this source is contingent upon impoundment. Furthermore, it is highly doubtful that water quality can be improved in this stretch of the Salt Fork to acceptable levels, even with 90 percent control of Area I. There is even a less possibility that the waters in Cimarron in this area can be improved to the desired level. Therefore, no benefits are computed for Enid.

0-5 - Ponca City

Subarea 0-5 is Kay County in north-central Oklahoma. The projected high quality water requirement is 40 mgd. Ponca City is the demand center with a 36 mgd 2020 requirement.

Ponca City is located adjacent to the junction of the Arkansas River and the Salt Fork, and near the Chikaskia River. Lake Ponca, with a yield of 15 mgd, and 74 wells, with a yield of 27 mgd, supply the demand center at present. The ground water is from the Alluvium of the Arkansas River and assumed to be of poor quality. However, limited data on 4 wells show this water to have 73 ppm chlorides.^{1/}

The Ark-Red project will have minimal effect on the quality of the project source, the Kaw Reservoir. Because of this, and the presence of a possible high quality ground water source, no benefits are attributable to the project.

0-6 - Tulsa

Subarea 0-6 consists of Osage, Creek, Washington, and Tulsa Counties in northeast Oklahoma. The projected high quality water requirement is 301 mgd. There are 2 demand centers--Tulsa with a 272 mgd requirement and Bartlesville with a 27 mgd requirement. Other municipalities have a 2 mgd requirement which may be satisfied by existing sources.

Bartlesville is adjacent to the Caney River and has a present surface source, with a firm yield, of 15 mgd. The unmet 2020 requirement of 12 mgd may be obtained from Sand Reservoir with or without the proposed quality control structures.

Tulsa's present source of water is Lake Spavinaw and the Grand River with a combined dependable yield of 132 mgd. The city has firm commitments for an additional 47 mgd from Oologah Reservoir on the Verdigris River. Proposed reservoir sites on Caney River and Bird Creek, and/or additional storage in Oologah Reservoir, could satisfy the unmet 93 mgd requirement. With the quality improvement provided by the Ark-Red project, Keystone Reservoir could be used as a source of supply.

Oologah Reservoir is given as the alternate source in absence of the project. Its use requires on stream transmission and a 12 mile pipeline from the nearest point on the Verdigris River to Tulsa.

The historic minimum mean monthly flow of the Arkansas River, the project source, at Tulsa is 89.5 cfs or 59 mgd. Keystone Reservoir storage is necessary to obtain a dependable yield of 93 mgd at Tulsa. Tulsa would need storage rights in Keystone Reservoir to develop the 34 mgd of additional yield. Complete on stream transmission eliminates any transmission cost. The water quality in the Arkansas River, below Keystone Reservoir, will be suitable under the following conditions: 90 percent control of natural salt loads in Areas I, II, and III; no control of the natural salt load from Minnescah; and 85 percent control of the manmade load.

0-8 - Oklahoma City

Subarea 0-8 consists of Canadian, Oklahoma, and Cleveland Counties. The projected municipal and industrial high quality water requirement is 318 mgd. The assumed demand center is the Oklahoma City-Norman area.

The North Canadian, Canadian, and Little Rivers flow through, or are adjacent to, the Oklahoma City-Norman area. The North Canadian, with off-stream storage, presently has a dependable yield of 45 mgd. Developed ground water yields an additional 67 mgd. Oklahoma City has a commitment for 45 mgd from Atoka Reservoir on Boggy Creek. Norman, Del City, and Midwest have commitments for 26 mgd from the authorized Norman Reservoir on Little River.

Average discharges on the Canadian River and the Cimarron River exceed the 2020 unsatisfied requirement for high quality water. The Cimarron River, a project stream, with 90 percent reduction in Area II and III, 75 percent reduction of Area IV, and 85 percent reduction of the manmade sources would still not be of satisfactory quality. The Canadian River, a nonproject stream, has only manmade chloride pollution which, if reduced by 85 percent, would improve its waters to acceptable standards.

The alternate source, to satisfy the unmet 2020 water requirement of 134 mgd, is Tuskahoma Reservoir on the Kiamichi River. Transmission losses over the 162 mile distance to the demand center requires pumpage of 146 mgd. 2/

The project source, Keystone Reservoir, has a transmission distance of 85 miles. The quality of waters stored in Keystone is acceptable with 90 percent control of Areas I, II, and III, and 85 percent control of the manmade load.

0-9 - Duncan

Subarea 0-9 consists of McClain, Caddo, Grady, Garvin, Stephens, and Murray Counties in south-central Oklahoma. The 2020 high quality water requirement for all municipalities is 39 mgd. Duncan and Chickasha are the two largest cities in the subarea. Chickasha is adjacent to the Washita River on which it has an impoundment capable of supplying its 2020 requirements. Duncan has a 2020 requirement of 18 mgd, and is the only potential benefit area in the subarea.

Duncan's present supply is obtained from Duncan Lake and Chisholm Trail Lake which have a combined dependable yield of 3 mgd. Beaver Creek, Mud Creek, and Wildhorse Creek, tributaries to the Red River, drain the area surrounding Duncan. The salt load in these creeks is manmade. The Red River is the nearest project stream. Duncan is negotiating for 17,590 acres of storage with a dependable yield of 16 mgd in a reservoir proposed under Public Law 83-566 on Black Bear Creek, 18 miles east of the city.

The alternate source is Hennepin Reservoir on Wildhorse Creek, some 35 miles from town. Wildhorse Creek contains manmade salt pollution; however, 85 percent reduction will lower the chloride concentration to acceptable levels.

The project source is the Red River which has sufficient flow to meet Duncan's 2020 requirements. The minimum transmission distance is 25 miles. The projected quality of Red River water will be fair with 90 percent removal of the natural salt pollution and 85 percent removal of the manmade salt pollution. Limited quality data precludes the development of chloride duration curves; however, it is estimated that municipal water of suitable quality will be possible when mixed with present sources.

0-10 - Lawton

Subarea 0-10 is Comanche County in southwest Oklahoma. The municipal and industrial high quality 2020 water requirement is 47 mgd, with the assumed demand center at Lawton, Oklahoma.

Lawton is in Cache Creek drainage, adjacent to Beaver Creek, both of which are tributary to the Red River. Lake Lawtonka, and Elmer Thomas Lake in the Wichita Mountains supply a total dependable yield of 11 mgd. Cache Creek Reservoir, under construction, will have a dependable yield of 9 mgd. The unsatisfied 2020 requirement is 27 mgd.

The alternate source is Waurika Reservoir on Beaver Creek. The reservoir, a U.S. Bureau of Reclamation proposed project, has adequate quality and quantity of supply. ^{3/} The transmission distance to Lawton is 26 miles.

The project source is the Red River below the mouth of the Wichita River which is 34 miles from Lawton. At this point, return flow from Wichita Falls will assure adequate minimum flows in the Red River. The average discharge in the Red River is approximately 1,000 mgd at this point. The average concentration of chloride will be fair, with 90 percent removal of loads from natural salt sources, and 85 percent removal of manmade pollution. Insufficient data precludes determination of chloride duration curves; however, suitable quality water may be obtained by mixing Red River water with present sources.

0-11 - Altus

Subarea 0-11 is Jackson County in southwest Oklahoma. The municipal and industrial high quality 2020 water requirement is 8 mgd with the demand center at Altus, Oklahoma.

Altus is adjacent to the Salt Fork of the Red River and both the Red River and the North Fork of the Red River flow nearby. The city presently has a right and an allocation of 4,800 acre-feet from Altus Reservoir. Transmission losses reduce the supply reaching the city to about 4 mgd, leaving an unmet 2020 requirement of 4 mgd. The Salt Fork of the Red River, 3 miles west of Altus, has an average flow of 94 cfs for the 13 years of record at Mangum, Oklahoma. The quality of this stream, as determined by 57 grab samples, averages 192 ppm of chloride with a range from 355 ppm to 40 ppm. ^{4/}

The alternate source is Mountain Park Reservoir which requires a transmission distance of 18 miles. The chloride quality of this source is 186 ppm maximum, 6 ppm minimum, and a weighted average of 27 ppm.^{5/}

The nearest project stream, the North Fork of the Red River, is 9 miles east of Altus with an average flow of 370 cfs for 15 years of record. However, even if 90 percent of the chloride loads from Area VI and 85 percent of manmade salt pollution is removed, these waters will not meet assumed quality standards. Available data precludes the computation of a chloride duration curve.

Inadequate quality improvement in the North Fork and the magnitude of transmission costs from other project sources precludes benefits to the project at Altus.

0-13 - Ardmore

Subarea 0-13 is Carter County in south-central Oklahoma. The total projected high quality water requirement for the subarea is 15 mgd. Ardmore, the demand center, is located on the drainage divide between Caddo Creek, a tributary to the Washita River, and Lake Murray. The city obtains its water supply from Mountain and City Lakes with a combined yield of 6 mgd. Wells yield an additional 1 mgd for smaller municipalities in the subarea.

The alternate source for the unsatisfied 2020 requirement of 8 mgd is Arbuckle Reservoir with transmission of 17 miles between the dam site and the city of Ardmore.

The nearest project source is Lake Texoma, 16 miles to the southeast. The storage cost in Lake Texoma is less than the additional transmission cost to the Red River above the lake. The chloride concentration in Texoma, with 85 percent control of manmade load at Gainesville and Durwood, 90 percent control of Areas V, VI, VIII, IX, XIV, and XV, and 50 percent control of Areas VII, and XIII will be less than 185 ppm all the time, and less than 100 ppm 80 percent of the time.

0-19a - Poteau

Subarea 0-19a is composed of four counties--Sequoyah, Haskell, Latimer, and LeFlore, located in east-central Oklahoma. The subarea has a total projected high quality water requirement of 32 mgd. A major portion of this demand, 25 mgd, is attributed to projected pulp and paper requirements. Examination of present sources shows yields sufficient to meet projected municipal demands.

The alternate source to supply 25 mgd needed for pulp and paper production is a reservoir on Brazil Creek, a tributary of the Poteau River. Brazil Creek water quality data are not available; however, it is assumed to be of similar quality to that of the Poteau River below Wister Dam, i.e., total dissolved solids concentration ranging from 56 to 108 ppm.

The project source is the stream reach of the Arkansas River between Webbers Falls and Van Buren which will have an average chloride concentration of 60 ppm and a total dissolved solids concentration of 320 ppm, assuming 85 percent removal of the manmade and 90 percent removal of the natural pollution. This quality is considered satisfactory for pulp and paper usage.

Since the mill in this subarea is not established, a new mill could locate equidistant from the project or alternate water source and, therefore, costs of transmission are not considered in determining benefits. The time a new mill would begin operation is not projected, but the average water requirement is assumed at half of the 2020 requirement for purposes of benefit computation.

T-8 - Wichita Falls

Subarea T-8 includes the Standard Metropolitan Statistical Area, Wichita County, which borders the Red River in north-central Texas. The projected high quality water requirement for this subarea is 90 mgd.

Wichita Falls, the demand center, is located on the Wichita River about 25 miles upstream from its confluence with the Red River. The city presently obtains its water supply from Lake Kickapoo and Lake Wichita, with a total combined firm yield of 22 mgd. However, the city recently received State approval on its request to build a reservoir at the Halsell site on the Little Wichita River. ^{6/} This reservoir will add an additional 38 mgd to the present supply. Other

municipalities in the subarea have sources presently yielding 3 mgd. The unmet 2020 requirement is 27 mgd for the subarea.

The alternate source is a reservoir at the Ringgold site on the Little Wichita. Transmission of water 25 miles from this reservoir to Wichita Falls would be necessary.

The project source is Lake Kemp which has a firm yield of 50 mgd and is located about 35 miles up the Wichita River from Wichita Falls. Utilization of water from this source would allow on stream transmission. By reducing natural and manmade brine pollution in the Wichita basin by 90 and 85 percent, respectively, and mixing water from Lake Kemp with present supplies, a chloride concentration of 200 ppm or less over 90 percent of the time may be expected. In comparison with the alternate supply, a chloride concentration of 45 ppm could be expected by mixing water from Ringgold with the present supply. Water from either plan would be satisfactory for most municipal and industrial needs.

T-11 - Gainesville, Sherman-Denison

Subarea T-11 is composed of two counties--Cooke and Grayson, adjoining the Red River near Lake Texoma. Two major water demand centers (Gainesville and Sherman-Denison) are included in the subarea.

Sherman-Denison, two cities in the eastern portion of the sub-area, have a combined projected high quality demand of 27 mgd. At present, municipal supplies with average chloride concentrations of 250 ppm are capable of yielding 8 mgd; however, the city of Denison has contracted for an additional 21,300 acre-feet of storage in Lake Texoma, and the city of Sherman has submitted a request for 41,000 acre-feet of storage. Since this demand area now has sufficient yield to meet projected demands, and plan to utilize Red River water, with or without the project, benefits are indeterminate.

The city of Gainesville, in the western portion of the subarea, has a 2020 high quality water requirement of 10 mgd. The city's current water needs are supplied from a well system capable of yielding 3 mgd.

The remaining unsatisfied need of 7 mgd may be met by using water from either the Red River (the project source) or from Aubrey Reservoir (the alternate source). Water from the Red River could be taken directly from the stream without storage costs. Transportation distances would be 15 miles from Aubrey Reservoir and 8 miles from the Red River.

The quality of water in the Red River at Gainesville, with removal of 90 percent of the natural and 85 percent of the manmade salt pollution, will be fair. The water from this project source, mixed with present supplies, will be satisfactory for most municipal and industrial needs.

T-12 - Dallas and Fort Worth

Subarea T-12 includes the Dallas and Fort Worth Standard Metropolitan Statistical Area which is composed of six counties--Denton, Collin, Tarrant, Dallas, Johnson, and Ellis. Located in north Texas, in the upper reaches of the Trinity River basin, the subarea has a total projected municipal and industrial process water requirement of 1,129 mgd for the year 2020.

The subarea presently has a firm water supply yield of 306 mgd from 10 reservoirs and a number of wells. An additional 323 mgd has been firmly committed, giving a total yield of 629 mgd, as shown:

Existing Supplies	251 mgd
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<u>Reservoirs</u>	
-------------------	--

Garza-Little Elm	
Grapevine	
Lavon	
Bridgeport	
Boyd	
Benbrook	
Eagle Mountain-Lake Worth	
Arlington	
Waxahachie	

<u>Ground Water</u>	55 mgd
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Firmly Committed Supplies	
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<u>Reservoirs</u>	323 mgd
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Cedar Creek	
Iron Bridge	

TOTAL	629 mgd
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Two possibilities exist for supplying the remaining unsatisfied need of 500 mgd (774 cfs). The first involves diversion of water from the Red River, a project source, to the Trinity River basin, a distance of 23 miles. The second water supply plan, the alternate source, utilizes water from Boswell Reservoir on Muddy Boggy Creek to the Trinity River basin, a distance of 70 miles.

Previous studies by a consulting engineering firm and subsequent discussions between this firm and the Corps of Engineers show that use of the Red River water by the City of Dallas could best be accomplished by taking water directly from Lake Texoma. ^{1/} This is because the cost of a low head holding reservoir below Texoma and increased power for pumping exceed storage costs in Texoma. ^{8/} Benefits are therefore computed for Subarea T-12 based on a cost of storage in Texoma as computed by the Corps of Engineers in the earlier study. ^{1/} This plan presumes that the Red River Compact negotiations, currently underway, will by the year 2020 allocate yields of Texoma equitably between Oklahoma and Texas and Dallas-Fort Worth will be able to obtain the necessary water to meet 2020 requirements.

With 85 percent control of upstream manmade pollution and 55 percent control of natural pollution, a chloride concentration in Texoma of less than 182 ppm may be expected 99 percent of the time and a concentration of less than 100 ppm 77 percent of the time. This quality is considered acceptable for projected uses.

Thorough mixing of waters from Muddy Boggy and Clear Boggy Creeks indicates an average chloride concentration in Boswell Reservoir can be expected to be below 250 ppm. Samples taken from Muddy Boggy Creek show average chloride concentrations of less than 50 ppm; however, samples from Clear Boggy Creek indicate average chloride concentrations surpass the recommended drinking water limits.

A-3 - Van Buren

Subarea A-3 consists of Crawford, Franklin, Johnson, Pope, Logan, Scott, Yell, Perry, Conway, Van Buren, Cleburne, and Faulkner Counties in west-central Arkansas. The 2020 water requirement is 97 mgd for the subarea. No municipality within this large rural subarea presently requires as much as 1 mgd; therefore, no municipal demand centers are assumed for future needs. The large forest resource, however, and assumed completion of the Arkansas Navigation Project indicate the development of pulp and paper mills, with a 2020 requirement of 70 mgd and a supporting labor force with a requirement of 2 mgd. The pulp and paper mills are assumed to locate in, or adjacent to, the counties south of the Arkansas River which contain most of the growing stock in the subarea, and within easy access to the transportation and waste assimilating potential of the Arkansas River.

There are numerous tributaries to the Arkansas River in the subarea on which surface impoundments would satisfy the future pulp and paper water requirements. The alternate sources of water supply are surface storage on these tributaries. It is assumed that sites

in this area would be similar in cost to the Brazil Creek Reservoir site in Subarea O-19a. Mill location near the reservoir would make water transportation cost insignificant.

The project source is the Arkansas River which has sufficient quantity, and under the assumed improvements, adequate quality for the pulp and paper industry. Mill location near the river would make transmission cost insignificant.

The times these mills would begin operation are not projected, but the average water requirement is assumed to be half the 2020 requirement for the purpose of benefit computation.

A-4 - Fort Smith

Subarea A-4 is Sebastian County in eastern Arkansas. The projected water requirement is 26 mgd with the demand center at Fort Smith.

Fort Smith is on the south bank of the Arkansas River and Van Buren, on the adjacent north bank, obtains its water from Fort Smith. Van Buren, in Subarea A-3, has a 2020 water requirement of 2 mgd. The present sources of supply for Fort Smith and Van Buren are Lake Fort Smith, Frog Bayou, and Spring Lake, which have a combined dependable yield of 30 mgd. Although sources have sufficient yield to meet the combined municipal requirement of 28 mgd, they (and the present treatment plant) are 22 miles from, and 250 feet above, Fort Smith. The finished water pipeline is basically 27 inches in

diameter and provides a gravity capacity of only 11 mgd. A booster pump on the pipeline increases this capacity to 18 mgd to meet peak loads in the distribution system.

The cost of using the present source as the alternate source is an additional gravity pipeline, 33 inches in diameter, capable of delivering 17 mgd.

The project source for Fort Smith-Van Buren is the Arkansas River which will have water of sufficient quantity, with the proposed improvement, adequate quality. The transmission cost is minor.

L-1 - Shreveport

Subarea L-1 consists of Caddo, Bossier, and Webster Parishes in northwest Louisiana. The 2020 water requirements are 223 mgd with the demand center assumed to be at Shreveport.

Shreveport is on the west bank of the Red River and Bossier City on the adjacent east bank. The present capacity of high quality surface and ground water available for municipal or industrial use is 123 mgd. Shreveport obtains its water from Cross Lake which has a storage capacity of 30 billion gallons.^{9/} This source is augmented by water from Twelve Mile Bayou which drains Caddo Lake and has a dependable yield of 53 mgd. The source of water supply for Bossier City is the Red River. The city is constructing sufficient off-channel storage to permit selective pumping from the river when its quality is acceptable. The total unsatisfied 2020 requirement for high quality water is 100 mgd.

The potential alternate sources of water in the subarea are numerous. In light of Bossier City's present plan, the alternate source selected by the Public Health Service is the use of the Red River with off-channel storage in Cross Lake. Chloride concentration in the Red exceeded the Public Health Service recommended limits for 87 days in 1954 at Shreveport. Cross Lake has sufficient storage capacity to permit bypassing the river during such periods of low quality. Transmission facilities, from the Red River to Cross Lake a distance of 3 miles, with a capacity of 150 mgd would be adequate to develop the required average daily yield of 100 mg.

The project source is the Red River which has sufficient quantity and will have acceptable quality with 90 percent removal of natural salt sources and 85 percent removal of manmade sources. Transmission of 3 miles to Cross Lake would be required.

L-6 - Alexandria

Subarea L-6 is Rapides Parish in central Louisiana. The 2020 high quality water requirement is 54 mgd with the assumed demand center at Alexandria.

Alexandria is located on the south bank of the Red River with Pineville on the adjacent north bank. Over 80 percent of the subarea's municipal population reside in these cities. The present municipal sources of supply have an estimated firm yield of 14 mgd.

There are three potential alternate sources of water supply near Alexandria and Pineville:

Iatt Lake Reservoir site has a maximum potential yield of 56.5 mgd. Water, on a controlled-flow basis, is available for sale under contract. Pineville could use these waters with Bayou Rigolette serving as a natural transmission canal.

Rapides Island is an alluvial area on the Red River west of Alexandria. A maximum of 20 water wells could be constructed to give a total yield of 14.3 mgd.

A series of four potential reservoir sites are along Bayou Rapides--Castor Lake near Boyce, Cotile Lake at Hot Wells, Brown Creek Lake east of Hot Wells, and Valentine Lake near Kincaid Bridge. Bayou Rapides affords on stream transmission to Alexandria. Maximum dependable yields for the four reservoirs are--Castor 29.3 mgd; Cotile 30.4 mgd; Brown 10.5 mgd; and Valentine 29.8 mgd.

The alternate source, selected on the basis of cost data supplied by the Louisiana Department of Public Works,^{10 11/} is an enlarged Iatt Lake with on stream transmission to the demand centers.

The project source is the Red River which has sufficient quantity and, under the assumed improvement conditions, good quality.

Municipal and Industrial Benefit Computations

Table VII-1 presents the cost parameters and develops the dollar benefits for the proposed water quality improvements in Arkansas and Red River basins. Of the 17 potential benefit areas examined, in the Ark-Red study area, 13 have benefits as determined by the alternate cost doctrine.

In relation to the storage cost data the Corps of Engineers stated:

"The accuracy of project cost data varies from preliminary estimates based on map data to actual construction costs of completed projects. Costs have been indexed to February 1962 price levels. For projects on which no previous estimates have been made, the annual charges were computed by applying the factor .040 to the gross cost of storage to obtain a lump-sum amount for interest and amortization, operation and maintenance, and major replacements." 12/

The transmission cost data are obtained from a Pipeline Conveyance Costs curve developed by the Office of Saline Water for quantities up to 100 mgd. ^{13/} For Dallas-Fort Worth and Oklahoma City, with requirements over 100 mgd, transmission cost are determined by calculating the average annual cost of the necessary pipelines and other transmission facilities. Transmission cost for Fort Smith, because of the gravity pipeline, is determined in a like manner. The data and method used in developing transmission cost for these three areas are presented in Appendix - Exhibit F. Using the cost data shown in Exhibit F, a comparison with the Pipeline Conveyance Costs curve for several quantities of flow, shows close agreement in terms of 2020 annual cost. However, the average annual cost, using one-half of the 2020 power cost to account for increases in pumpage from 0 to 100 percent of line capacity, varied from 85 to 90 percent of the 2020 annual cost. Ninety percent of the conveyance cost obtained from the curve are therefore used in calculating average annual transmission costs.

The first year that present or committed water sources would not meet "dry year" requirements are determined on a liberal straight line increase in requirements to the year 2020. The year of first need, as shown on Table VII-1, is 10 years in advance of this date which is in keeping with present waterworks practices in this country.

Table VII-1

2020 M & I Benefits to Water Quality Improvement

Subarea Reference City	Unmet 2020 Requirement (mgd)	Alternate Source and Project Source	Cost of Development (\$/1,000 gallons) Storage	Average Annual Cost (\$1,000)	Year of First Need	2020 Benefits (\$1,000)	
						Average Annual	1970 Worth
0-6 Tulsa ✓	93	Oologah Res. Keystone Res.	0.007 0.009	635 112	1995	523	196
0-8 Oklahoma City ✓	146	Tuskahoma Res. Keystone Res.	0.004 0.009	6,235 3,413	1985	2,822	1,566
0-9 Duncan ✓	15	Hennepin Res. Red River	0.046 0	731 310	1970	421	421
0-10 Lawton ✓	27	Waurika Res. Red River	0.046 0	914 603	1975	311	255
0-13 Ardmore ✓	8	Arbuckle Res. Lake Texoma	0.020 0.003	210 150	1970	60	60
0-19a Poteau ✓	25	Brazil Creek Res. Arkansas River	0.008 0	37 0	1970	37	37
T-8 Wichita Falls ✓	27	Ringgold Res. Lake Kemp	0.041 0	830 0	1990	830	378

Table VII-1 (Continued)

Subarea Reference City	Unmet 2020 Requirement (mgd)	Alternate Source and Project Source	Cost of Development (\$/1,000 gallons)		Average Annual Cost (\$1,000)	Year of First Need	2020 Benefits (\$1,000)	
			Storage	Trans- mission			Average Annual Worth	1970 Worth
T-11 Gainesville	7	Aubrey Res. Red River	0.015 0	0.0486 0.0261	162 66	1970	96	96
T-12 Dallas-Fort Worth	500	Boswell Res. Lake Texoma	0.003 0.003	0.0373 0.0122	6,817 2,236	1990	4,581	2,089
A-3 Van Buren	72	Tributary Res. Arkansas River	0.008 0	0 0	105 0	1970	105	105
A-4 Fort Smith	17	Lake Fort Smith Arkansas River	0 0	0.020 0	124 0	1970	124	124
L-1 Shreveport	100	Red River off-channel Storage Red River	0 0	0.0024 0.0027	133 98	1980	35	24
L-6 Alexandria	40	Iatt Lake Red River	0.0016 0	0 0	23	1970	23	23
Total	1,077				9,968		23	5,374

Agricultural Benefits

Agricultural benefits attributable to the Ark-Red Quality Control Project are the differences in 2020 net returns between dryland and irrigated agriculture in the previously defined stream reaches made usable by Ark-Red project brine control works. Examination of projected stream quality and quantity and needed irrigation acreages in the study area confines agricultural benefits to the following major stream reaches.

1. Arkansas River from below Ponca City to Muskogee, Oklahoma.
2. Red River from Wichita Falls, Texas to Hugo, Oklahoma.

Under the assumed quantity and quality conditions, without the proposed Ark-Red brine control structures, acreages are allocated to individual watersheds. Any acreage thus left unserved by irrigation waters would remain in dryland production in absence of the project. Where improvement in projected quality will permit use of waters downstream from the 15 Ark-Red project areas (electrical conductivity reduced from over 1,000 micromhos to less than 1,000 micromhos) with an assumed 90 percent reduction of natural brines from delineated sources, benefits to agriculture will result. A discussion of stream quality at present and concentrations expected in the future is presented in the succeeding chapter.

Total acreages benefited by the proposed project appear by Type-of-Farming Areas in Table VII-2.

Table VII-2

Projected Acreages in Benefit Stream Reaches

<u>Type-of- Farming Area</u>	<u>Irrigated From Surface Sources</u>		<u>Increase</u>	<u>In Benefit Stream Reaches</u>
	<u>1959</u>	<u>Projected 2020</u>		
1	511	510	-1	
2	50	60	10	
3	3	18	15	
4	52	70	18	
5	3	31	28	10
6	3	48	45	15
7	8	43	35	15
8	3	108	105	
9	11	232	221	
10	7	178	171	
11	94	864	770	
Total	745	2,162	1,417	40

For each type-of-farming area where benefits would accrue from the water quality improvement project, an analysis is made to determine the net return to land risk and management for irrigated and nonirrigated cropping patterns. To provide benchmark data, a preliminary analysis of annual benefits per acre is made using present prices, costs, yields, and cropping patterns. A summary of these calculations appears in Table VII-3. For actual benefit computations, however, projected prices, costs, and yields are used.

Table VII-3

Net Returns From Irrigated and Dryland Farming, Using
Present Prices, Costs, and Yields

<u>Crop</u>	<u>Per- cent</u>	<u>Yield</u>	<u>Income Per Acre</u>	<u>Costs Per Acre</u>	<u>Net Returns</u>	<u>Net Return Difference</u>
<u>Type-of-Farming Area 5</u>						
<u>Dryland</u>						
Wheat	40	20 Bu.	41.90	28.10	13.80	14.20
Soybeans	35	20 Bu.				
Corn	15	35 Bu.				
G. Sorghum	10	30 Bu.				
Alfalfa	5	2.0 T.				
<u>Irrigated</u>						
Alfalfa	50	3.0 T.	69.90	41.90	28.00	
Pasture	25	5 AUM				
G.Sorghum	10	40 Bu.				
Corn	10	45 Bu.				
Wheat	5	25 Bu.				
<u>Type-of-Farming Area 6</u>						
<u>Dryland</u>						
Corn	25	30 Bu.	55.20	34.10	21.10	14.40
G.Sorghum	25	30 Bu.				
Cotton L.	20	250 Lbs.				
Cotton S.		425 Lbs.				
Wheat	20	19 Bu.				
Peanuts	10	1,200 Lbs.				
<u>Irrigated</u>						
Alfalfa	55	3.5 T.	93.50	58.00	35.50	
Pasture	10	5 AUM				
G.Sorghum	10	60 Bu.				
Cotton L.	10	400 Lbs.				
Cotton S.		720 Lbs.				
Wheat	10	33 Bu.				
Peanuts	5	1,500 Lbs.				

Table VII-3 (Continued)

<u>Crop</u>	<u>Per- cent</u>	<u>Yield</u>	<u>Income Per Acre</u>	<u>Costs Per Acre</u>	<u>Net Returns</u>	<u>Net Return Difference</u>
<u>Type-of-Farming Area 7</u>						
<u>Dryland</u>						
Cotton L.	30	300 Lbs.	66.80	37.10	29.70	
Cotton S.		540 Lbs.				
Wheat	30	30 Bu.				
G.Sorghum	25	40 Bu.				
Corn	10	30 Bu.				
Alfalfa	5	2 T.				
						14.90
<u>Irrigated</u>						
Alfalfa	30	3.5 T.	120.55	75.95	44.60	
Cotton L.	20	450 Lbs.				
Cotton S.		810 Lbs.				
Peanuts	15	1,500 Lbs.				
Vegetables	10	100 CWT				
G.Sorghum	10	50 Bu.				
Wheat	10	30 Bu.				
Corn	5	50 Bu.				

Projected prices, based on an all product index of 235 (1910-1914 = 100), are those published by the U.S. Department of Agriculture in 1957.^{14/} These projections represent the level of prices expected to prevail over a long period of time, under assumptions of relatively high employment, a trend toward peace, continued population and economic growth, a reduction of farm surpluses and a stable general price level. Rapidly changing technology in agriculture and the associated change of price-cost relationship, however, could result in prices different from those projected.

Projected yields and fertilizer needs, developed on the basis of work done by Texas A & M ^{15/} are fitted to each type-of-farming area on the basis of rainfall, climate, and soil types. Only those dryland and irrigated yield projections for soil types which would normally be irrigated are extracted from the Texas data for application to the study area.

Projected cropping patterns for each type-of-farming area are based on data developed for the U.S. Study Commission-Texas.^{16/} These data estimate the crop increases (both irrigated and dryland) needed to supply future demands for food and fiber. Crop increases are applied to present irrigated and dryland cropping patterns to produce future cropping patterns for each type-of-farming area.

Projected production costs are developed on the basis of present costs since no projected cost data are available. The procedure involves estimating costs of production for future yields from present costs associated with various yield levels, and adjusting these costs by a prices paid by farmers index of 265. Present production cost data, developed from various sources,^{17 18 19 20 21 22/} include cost of land development, pumping and delivery, labor, seed, fertilizer, insecticide, repair, depreciation, custom work, interest, machinery, taxes, water, and miscellaneous.

A summary of calculations used to arrive at annual benefits per acre appear in Table VII-4.

Table VII-4

Net Returns From Irrigated and Dryland Farming, Using
Projected Prices, Costs, and Yields

<u>Crop</u>	<u>Per- cent</u>	<u>Yield</u>	<u>Income Per Acre</u>	<u>Costs Per Acre</u>	<u>Net Returns</u>	<u>Net Return Difference</u>
<u>Type-of-Farming Area 5</u>						
<u>Dryland</u>						
Soybeans	35	28 Bu.	55.20	41.00	14.20	17.80
Wheat	30	20 Bu.				
Corn	20	55 Bu.				
G.Sorghum	10	51 Bu.				
Alfalfa	5	2.3 T.				
<u>Irrigated</u>						
Alfalfa	55	3.5 T.	104.60	72.60	32.00	
G.Sorghum	25	124 Bu.				
Corn	15	110 Bu.				
Wheat	5	35 Bu.				
<u>Type-of-Farming Area 6</u>						
<u>Dryland</u>						
Corn	30	55 Bu.	81.10	62.70	18.40	21.25
G.Sorghum	30	51 Bu.				
Cotton L.	30	417 Lbs.				
Cotton S.		709 Lbs.				
Wheat	10	20 Bu.				
<u>Irrigated</u>						
Alfalfa	40	4.2 T.	165.15	125.50	39.65	
G.Sorghum	30	134 Bu.				
Cotton L.	30	830 Lbs.				
Cotton S.		1,494 Lbs.				
Wheat	5	35 Bu.				
Corn	5	110 Bu.				

Table VII-4 (Continued)

<u>Crop</u>	<u>Per-</u> <u>cent</u>	<u>Yield</u>	<u>Income</u> <u>Per Acre</u>	<u>Costs</u> <u>Per Acre</u>	<u>Net</u> <u>Returns</u>	<u>Net Return</u> <u>Difference</u>
<u>Type-of-Farming Area 7</u>						
<u>Dryland</u>						
Cotton L.	30	417 Lbs.	76.85	59.55	17.30	22.20
Cotton S.		709 Lbs.				
G.Sorghum	25	51 Bu.				
Corn	20	55 Bu.				
Wheat	20	20 Bu.				
Alfalfa	5	2.3 T.				
<u>Irrigated</u>						
Alfalfa	30	4.2 T.	161.80	122.30	39.50	
Cotton L.	25	830 Lbs.				
Cotton S.		1,494 Lbs.				
G.Sorghum	20	124 Bu.				
Vegetables	15	250 CWT				
Corn	10	110 Bu.				

Utilizing data developed in Tables VII-2 and VII-4, estimated project benefits to agriculture are presented in Table VII-5.

Table VII-5

Estimated Annual Benefits to Agriculture

Type-of-Farming Area	Acres (1,000)	Per Acre (\$)	Total (\$1,000)	Average Annual Benefit (\$1,000)	Year of First Water Use	1970 Worth of Average Annual Benefit (\$1,000)
5	10	17.80	178	89	2000	28
6	15	21.25	319	159.5	2000	49
7	15	22.20	333	166.5	1995	62
Study Area	40		830	415		139

2070 Projections

Late in the progress of this evaluation, it was requested that benefits be extended for an additional 50 years beyond the originally selected terminal date of 2020. Since predictivity of future conditions decreases in accuracy geometrically as the projection period is extended, an overall study area evaluation in relation to the Nation is deemed the most reliable. Because of increasingly efficient communication and transportation networks, industrial expansion and population increases (both of which govern water demands) are expected to depend less on location factors associated with resources or markets.

This tendency is illustrated by comparison of historical trends of various parameters in different regions of the country. Regional projections, extremely variable in the past, are tending toward a common growth rate. Assuming this tendency toward homogeneity will be even more pronounced in the future, ratios of estimations for 2020 are also considered applicable to 2070.

Population

Many articles have been written recently about the world and national "population explosion." Almost invariably these estimations of future population assume growth rates of the last 20 years will continue indefinitely. If this does occur, by 2070 this country will have a population of 900 million or an average population density of 300 persons/mi.² in continental United States. This level of population, however, seems inconceivable in the light of our present way of living. A "more probable" 2070 population for continental United States of 750 million is anticipated. The rate of growth thus established when applied to the 2020 study area population of 24.5 million results in a projected 2070 total study area population of 42 million.

Water Demands

Projected 2020 water demands for the study area are 4.95 bgd for municipal and industrial process purposes. Based on the total study area population, overall unit demands for these uses are 205 gpcd. Presuming these demands will be more closely related to the

total population, and the overall unit demand will be unchanged, the 2070 study area municipal and industrial requirements, exclusive of cooling water, are expected to average 8.6 bgd.

No increase is anticipated for irrigation between 2020 and 2070; therefore, these water demands are expected to remain approximately the same, or possibly be reduced, because of higher efficiencies in production of food and fiber.

Benefits

Water demands for 2070 are expected to be met by extension of methods employed to satisfy the 2020 demands. The portion of study area's 2020 high quality municipal and industrial demands satisfied from project sources is 22 percent. Expectations are this ratio will increase to 50 percent by 2070. Application of this ratio to 2070 study area water needs results in a total of 4,300 mgd that is expected to be obtained from project sources. The net increase in water requirements supplied by project sources from 2020 to 2070 then is 3,200 mgd.

The average annual 2020 municipal and industrial benefit per mgd is \$11,300 for project sources. Application of this rate to 2070 project source demands results in an average annual 2070 benefit of \$36,200,000. Present worth (1970) of this benefit, discounted from 2020 (the year of first need), at 4 percent is \$5,100,000. Total municipal and industrial benefits to the year 2070 then are \$10,426,000 and total benefits, including agricultural benefits are \$10,565,000.

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VIII. STREAM QUALITY MAINTENANCE

The major factor in a continuing program of pollution abatement is the maintenance of stream quality after initial pollution controls have been achieved.

The program under study, concerned with an abatement of chloride pollution in the Arkansas and Red River basins, involves two facets. One is that of legislative control placed on manmade pollution. The second involves controlling natural pollution at its source. Benefits for the latter are determined in this study.

In order to better illustrate the problem involved in achieving and maintaining satisfactory stream quality conditions, an analysis of the present quality conditions and the effect proposed controls will have on future quality, follows:

Present Quality

The presence of dissolved chlorides in waters of the Arkansas and Red River basins are attributed to three major sources of pollution:

Natural--Brines emanating from identified natural salt formations. Chloride tonnages used in computations are the latest estimates of average loads contributed by the 15 delineated salt source areas (see Chapter III).

Manmade--Chloride tonnages generally attributed to uncontrolled oilfield brines, but may include some undelineated manmade or natural pollution.

Municipal--Manmade chloride pollution contributed through municipal waste disposal facilities. Tonnages of chlorides added to the stream from this source are estimated, using the following assumptions:

- (1) Chloride concentration of a municipal water supply is increased 50 ppm with use.
- (2) Eighty percent of the water withdrawn by a municipality is returned to the stream.

In the Arkansas River basin there are five areas in which a significant municipal and industrial benefit will accrue to water quality improvement. Since the only large concentrations of chloride pollution in the basin occur above Keystone Reservoir, quality maintenance in upstream drainage would also provide good quality water for downstream demand areas.

In the Red River basin there are eight areas where significant municipal and industrial benefit is possible if good quality water is made available. Since most of the chloride pollution occurs in the

upper drainage area of the Red River, maintenance of good quality at Texoma Reservoir would automatically provide water of good quality for downstream users.

Projected Quality

Estimations of future chloride concentrations at these key checkpoints, plus upstream and downstream locations on the Arkansas and Red Rivers, are presented in Table VIII-1. Data presented are derived from preliminary chloride-duration curves prepared by the Tulsa District office of the Corps of Engineers for the Kaw, Keystone, and Texoma Reservoirs. The remaining estimations are based upon available quantity and quality data.

The bases for projecting future stream quality assume the following pollution controls may be achieved in areas where needed.

Natural chloride pollution from project area can be reduced by as much as 90 percent.

Manmade chloride pollution from oilfield brines and some other industrial sources can be reduced by up to 85 percent.

Undelineated natural sources of pollution will not be reduced.

The degree of control required in the stream reaches mentioned is a function of the stream quality desired for a given percent of time. Since mean monthly flow and concentration data are used in arriving at these estimated chloride levels, durations refer to percent of months.

Table VIII-1

Chloride Ion Concentration vs. Duration for Project Water Sources
(mean monthly ppm equalled or exceeded)

Project Water Supply Source	Existing Conditions		100% of Project Pollution Plus 15% of Manmade Pollution		10% of Project Pollution Plus 15% of Manmade Pollution	
	50% of Months	10% of Months	50% of Months	10% of Months	50% of Months	10% of Months
<u>Arkansas River Basin</u>						
Eaw Reservoir*	310	430	80	120	60	90
Keystone Reservoir**	500	900	370	670	70	130
Ark. R. @ Van Buren	282	593	164	345	< 70	< 100
<u>Red River Basin</u>						
Lake Kemp	1,870	3,360	1,010	1,770	150	200
Red R. @ Gainesville	740	1,100	580	860	180	265
Lake Texoma	265	370	220	280	85	120
Red R. @ Shreveport	81	360	< 80	< 250	< 75	< 100

* With reservoir in operation.

**With both reservoirs in operation.

To assure complete utility of water for both municipal and industrial purposes, a concentration of 100 ppm is established as the desired goal; however, should this goal not be possible under even maximum assumed controls, 250 ppm or less at least 90 percent of the months is the minimum quality considered acceptable in determining benefits.

The discussion thus far has been concerned with present conditions and possible conditions achievable through project and legislative controls. After these controls have been applied, the affect of future increased municipal return flows must be considered. As pointed out earlier, the chloride concentration of a municipal water supply is assumed to increase by 50 ppm with use. If it is also assumed that all upstream municipal contributions will have an accumulative effect on the downstream chloride loads (that is, no upstream tonnages will be diverted from the streams), total municipal chloride tonnages will be as shown in Table VIII-2.

Table VIII-2

2020 Municipal Chloride Loads
(T/D)

<u>Location</u>	<u>Average Load</u>
<u>Arkansas River</u>	
Arkansas City, Kansas	355
Tulsa, Oklahoma	397
Van Buren, Arkansas	569
<u>Red River</u>	
Gainesville, Texas	52
Colbert, Oklahoma	63
Shreveport, Louisiana	127

If it is further assumed that 1/3 of the 2020 municipal chloride load is represented in quality data used to arrive at concentration estimates in Table VIII-1, average (50% of months) concentrations would be increased from 70 to 84 ppm in Keystone Reservoir and from 85 to 89 ppm in Lake Texoma. These estimates are quite liberal,

especially in the Arkansas River, because a significant portion of the upstream loads very likely would be diverted with irrigation or other waters before reaching downstream checkpoints. These increases in chloride concentration would not materially reduce the utility of waters for municipal and industrial or irrigation purposes.

IX. APPENDIX

Exhibit A-1

Economics and Population

In the final report this exhibit will contain tabular base data used in making economic and population projections.

Municipal Water Demands

Present

Municipal water use, as defined for the purpose of this report, includes residential, public, and commercial use; plus those industrial uses which can reasonably be reflected in an overall per capita use figure. Examples of the latter are soft-drink bottling works and milk processing plants whose products are consumed mainly by the people residing within the subarea under study.

Table B-1 presents data on municipal water supplies within the Ark-Red study area. Pertinent information is presented by State and subarea for each public water supply serving a population of 1,000 or more. It will be noted that 432 of the 658 individual supplies listed utilize ground water sources exclusively. The remainder obtain water from surface sources (170 systems) or a combination of ground and surface sources. Municipalities relying solely on ground water are for the most part smaller communities in the western and extreme eastern portions of the study area where surface supplies are unavailable, unreliable, of unsuitable quality, or too expensive for smaller communities to develop.

Also listed for each supply are quality parameters usually associated with establishing the suitability of a source of supply for municipal purposes. Although quality of water may vary markedly in some supplies during seasons of the year, particularly those obtained from surface sources, these data are intended to represent as closely as possible average conditions. Where results of several samples were available, concentrations presented are averages; where no data were available, results are presented of analyses conducted upon samples from the same surface stream or the same ground water aquifer near the municipality; where no data or estimates are available, nothing is entered.

It will be noted that none of the potential benefit stream reaches delineated in Chapter III are listed in Table B-1 as a source of supply, except Denison and Bossier City. Although sufficient quantity of water could be developed in most of these streams, their generally poor quality has forced communities to seek other (ofttimes more distant and expensive to develop) sources to satisfy their increasing needs for water. Chapter VII lists 16 such locations in the study area and a water plan is developed for each.

Table B-1

EXHIBIT B-2

Municipal Water Supply Data									
State Subarea County Municipality	Present Average Demand (mgd)	Water Supply Quantity				Water Supply Quality (ppm)			
		Surface Water		Ground Water		Cl ⁻	SO ₄ ⁼⁼	Hardness (as CaCO ₃)	TDS
		Source	Yield (mgd)	Source	Yield (mgd)				
Colorado									
C-1									
Pueblo									
Pueblo	26.50	Arkansas R.	33.00			6	115	174	285
El Paso									
Colorado Spgs.	19.20	Fountain Cr., Blue & S. Platte R.	16.70			9	17	60	111
Manitou Spgs.	1.10	French & Ruxton Crs.				2	7	16	56
TOTAL	46.80		49.70						
Colorado									
C-2									
Elbert									
Lincoln				7 Wells	9.86	13	556	481	1,090
Limon	0.70								
Kit Carson				4 Wells	2.90	8	18	136	235
Burlington	0.30								
Cheyenne				4 Wells	1.44	1	13	132	187
Cheyenne Wells	0.12								
Kiowa				3 Wells	1.40	47	553	356	1,150
Eads	0.05								
Prowers				20 Wells	9.30	9	193	276	452
Lamar	0.85								
Holly	0.13			4 Wells	1.10	13	172	250	450
Hack									
Springfield	0.25			5 Wells	3.20	9	208	302	485
TOTAL	2.40				29.20				
Colorado									
C-3									
Huerfano									
Walsenburg	3.50	Cucharas R.	2.00			0	13	97	115
Custer									
Fremont									
Canon City	3.00	Arkansas R.	2.50			3	28	95	138
Florence		Newlin Cr.	1.15*			0	15	123	166
Chaffee									
Salida	1.50	S. Ark. R.	2.00	4 Wells		2	16	153	215
Buena Vista	0.20	Cottonwood Cr.	1.30	1 Well		0	4	40	57
Lake									
Leadville	2.00	Evans & Iowa Cr.	2.00			0	18	17	88
Park									
Teller									
TOTAL	10.20		10.95						
Colorado									
C-4									
Las Animas									
Trinidad	6.00	Purgatoire R. & Whiskey Cr.	8.00			1	6	76	98
Aguilar	0.05			Wells	0.05	3	50	193	286
Otero									
La Junta	2.70			10 Wells	10.00	44	875	848	1,660
Rocky Ford	2.00	Arkansas R.	2.30	2 Wells		38	768	808	1,440
Fowler	0.01			5 Springs	0.06	180	432	304	1,160
Crowley									
Ordway	0.20			2 Wells	0.20				
Hunt									
Las Animas	0.63			4 Wells	3.40	100	1,520	1,160	2,850
TOTAL	11.59		10.30		13.71				

* Estimated

Table B-1 (Continued)

EXHIBIT B-3

Municipal Water Supply Data									
State	Present	Water Supply Quantity				Water Supply Quality (ppm)			
Subarea	Average	Surface Water		Ground Water					
County	Demand	Source	Yield (mgd)	Source	Yield (mgd)	Cl ⁻	SO ₄ ⁼	Hardness (as CaCO ₃)	TDS
Municipality	(mgd)								
New Mexico									
NM-1									
Colfax									
Raton	0.90	Lake Malaga	4.00			2	10	96	123
Springer	0.10	Eagle Nest Lake	0.20			6	167	272	410
Mora									
San Miguel									
Las Vegas	1.20	Gallinas R.	1.95	4 Wells	1.57				
TOTAL	2.20		6.15		1.57				
New Mexico									
NM-2									
Union									
Clayton	0.60			7 Wells	1.25	14	44	275	315
Harding									
Quay									
Tucumcari	1.10			13 Wells	2.74	8	13	200	272
Curry									
Clovis	3.20			14 Wells	10.50	16	27	172	276
TOTAL	4.90				14.49				
Kansas									
K-1									
Greeley									
Tribune	0.25			Wells	0.88e	7	12	140	207
Wichita									
Leoti	0.10			Well	1.00e	10	19	152	246
Scott									
Scott City	0.46			Well	2.70e	17	40	198	363
Lane									
Dighton	0.25			Wells	1.30e	34	42	325	459
Hamilton									
Syracuse	0.25			Well	0.72e	4	79	176	303
Kearney									
Lakin	0.07			Wells	1.15e	9	30	160	236
Finney									
Garden City	2.00			Wells	5.25	28	189	266	530
Stanton									
Grant									
Ulysses	0.40			Wells	3.02e	24	157	304	462
Haskell									
Sublette	0.10			Wells	0.72e	10	44	150	243
Morton									
Elkhart	0.25			Wells	0.90e	20	88	288	426
Stevens									
Hugoton	1.50			Wells	2.90e	26	164	324	521
Seward									
Liberal	2.90			Wells	4.50e	15	84	230	365
TOTAL	8.53				25.04				
Kansas									
K-2									
Ness									
Ness	0.20			Wells	1.15e	37	137	372	588
Rush									
LaCrosse	0.15			Wells	1.25e	395	223	82	1,252
Pawnee									
Larned	1.50			Wells	3.95	77	662	800	1,272
TOTAL	1.85				6.35				

Table B-1 (Continued)

EXHIBIT B-4

Municipal Water Supply Data

State Subarea County Municipality	Present Average Demand (mgd)	Water Supply Quantity				Water Supply Quality (ppm)			
		Surface Water		Ground Water		Cl ⁻	SO ₄ ⁼	Hardness (as CaCO ₃)	TDS
		Source	Yield (mgd)	Source	Yield (mgd)				
Kansas									
K-3									
Hodgeman									
Jetmore	0.22			Wells	0.76e	58	141	446	687
Gray									
Cimarron	0.55			Wells	0.40	9	35	160	261
Ford									
Dodge City	1.50			Wells	4.05	17	70	238	353
TOTAL	2.27				5.21				
Kansas									
K-4									
Meade									
Meade	0.50			Well	1.80e	8	18	150	224
Clark									
Ashland	0.50			Wells	1.85e	34	342	564	805
Comanche									
Coldwater	0.15			Wells	0.80e	9	7	130	195
Harber									
Medicine Lodge	0.06			Wells	1.20e	16	33	194	274
Kiowa	0.18			Wells	1.90e	99	185	442	790
TOTAL	1.39				7.55				
Kansas									
K-5									
Edwards									
Kinsley	0.30			Wells	1.73	4	11	126	178
Kiowa									
Greensburg	0.25			Wells	2.00e	8	12	219	256
Pratt									
Pratt	1.60			Wells	6.40e	51	22	196	308
Stafford									
Stafford	0.20			Wells	1.08	113	15	214	432
St. John	0.22			Wells	2.25	29	17	184	298
Rice									
Sterling	0.50			Wells	1.15	93	88	260	548
Lyons	0.75			Wells	2.75	165	59	274	637
TOTAL	3.82				17.36				
Kansas									
K-6									
Barton									
Holsington	0.53			Wells	5.04	75	35	120	339
Ellinwood	0.42			Wells	1.30	92	635	642	1,305
Great Bend	2.75			Wells	9.94	149	164	298	699
TOTAL	3.70				16.28				
Kansas									
K-7									
Ellsworth									
Wilson	0.20			Wells	0.40e	62	66	344	578
Ellsworth	0.25			Wells	1.00e	118	179	135	536
McPherson									
McPherson	2.00			Wells	5.90	20	10	256	340
Lindsborg	0.38			Wells	2.90	79	159	488	753
Marion									
Peabody	0.15			Wells	0.43e	36	438	710	1,042
Marion	0.30	Mad Cr.	1.00e			153	843	1,099	1,563
Hillsboro	0.16			Wells	0.44e	65	1,386	1,670	2,360
Harvey									
Newton	2.50			Wells	2.50	11	22	150	242
Halstead	0.17			Wells	1.62	26	28	150	317
Sedgwick	0.10			Wells	0.85	46	130	454	622
Hesston	0.04			Wells	0.94e	42	35	250	514
TOTAL	6.25		1.00		16.98				

Table B-1 (Continued)

EXHIBIT B-5

State Subarea County Municipality	Present Average Demand (mgd)	Municipal Water Supply Data				Water Supply Quality (ppm)			
		Water Supply Quantity				Hardness			
		Surface Water		Ground Water					
		Source	Yield (mgd)	Source	Yield (mgd)	Cl ⁻	SO ₄ ⁼	(as CaCO ₃)	TDS
Kansas									
K-8									
Covley				Wells	4.32e	530	170	426	1,404
Arkansas City	1.50			Wells	3.89e	530	65	736	1,184
Winfield	1.60								
Butler									
Augusta	0.35	Impounded Res.	1.03e	Wells		330	233	186	983
El Dorado	0.75	Impounded Res.	2.46e	Wells		336	244	116	979
Sedgwick									
Wichita	28.75			91 Wells	84.00e	23	29	144	292
Haysville				Wells		147	162	134	519
Derby				Wells	0.07e	39	109	404	600
Reno									
Nickerson	0.10			Wells	0.90	249	295	408	1,162
Hutchinson	7.00			12 Wells	15.00e	168	130	334	751
TOTAL	40.05		3.49		108.18				
Kansas									
K-9									
Sumner									
Wellington	0.75	Impounded Res.	2.80e	Well		87	115	354	552
Caldwell	0.22			Wells	0.50e	31	62	276	390
Belle Plaine	0.14			Well	1.20e	25	20	156	287
Harper									
Anthony	0.50			Wells	1.22e	30	61	254	465
Harper	0.38			Wells	1.55e	22	18	184	315
Kingman									
Kingman	0.55			Spring & Wells	1.08e	13	13	112	206
TOTAL	2.54		2.80		5.55				
Kansas									
K-10									
Chautauque									
Sedan	0.15	Impounded Res.				10	26	114	150
Elk									
Howard	0.08	Impounded Res.	0.28e			10	26	120	171
Greenwood									
Eureka	0.35	Lake Eureka & Fall R.	0.35e			57	39	247	360
Madison	0.08			Wells	0.36e	23	27	379	455
Chase									
Cottonwood Falls	0.09			Wells	0.20e	17	70	216	539
Morris									
Council Grove	0.40	City Lake & Neosho R.	1.30e			8	38	132	184
TOTAL	1.15		1.93		0.56				
Kansas									
K-11									
Lyon									
Emporia	3.00	Neosho R. & Lake Kahola	4.50e			12	37	64	126
Coffey									
Burlington	0.10	Neosho R.	0.83e			103	107	288	567
Woodson									
Yates Center	0.20	Impounded Res.	0.69e			95	38	122	289
Allen									
Iola	0.70	Neosho R.	2.07e			22	71	62	183
Humbolt	0.25	Neosho R.	0.94e			25	66	154	260
Wilson									
Neodesha	0.50	Fall R. (imp.)	1.73e			47	31	300	338
Fredonia	0.50	Fall R. (imp.)	1.55e			85	51	156	700
Neosho									
Chanute	1.40	Neosho R.	3.14e			88	47	112	296
Erie	0.04	Neosho R.	0.62e	Well		34	80	100	255
Labette									
Parsons	2.00	Labette Cr. & Neosho R.	5.18e			8	92	193	397
Oswego	0.20	Neosho R.	0.96e			40	51	130	247
Chetopa	0.10	Neosho R.	0.52e			30	154	226	383

Table B-1 (Continued)

EXHIBIT B-6

Municipal Water Supply Data										
State Subarea County Municipality	Present Average Demand (mgd)	Water Supply Quantity				Water Supply Quality (ppm)				
		Surface Water		Ground Water		Hardness				
		Source	Yield (mgd)	Source	Yield (mgd)	Cl ⁻	SO ₄ ⁼	(as CaCO ₃)	TDS	
Kansas										
K-11 (Continued)										
Cherokee				Wells		12	61	224	282	
Galena	0.35			Wells	0.65e	71	70	218	548	
Columbus	0.35			Wells	1.00e	81	75	228	419	
Maxter Spring	0.05									
TOTAL	9.74		22.73		1.65					
Kansas										
K-12										
Montgomery										
Independence	1.50	Elk & Verdigris				120	40	250	300	
		Ra. (Imp.)	3.45e			105	48	288	508	
Coffeyville	3.00	Verdigris R. (Imp.)	6.84e			95	40	104	291	
Cherryvale	0.25	Verdigris R.	1.38e			150	23	220	530	
Caney	0.30	L. Caney R.	0.69e							
TOTAL	5.05		12.36							
Kansas										
K-13										
Crawford										
Arma	0.04			Wells	0.30e	225	57	260	776	
Pittsburg	1.60			Wells	3.11e	87	86	297	531	
Girard	0.25			1 Well	1.35e	523	124	455	1,387	
Frontenac	0.20			Wells	0.86e	112	36	218	491	
TOTAL	2.09				5.62					
Oklahoma										
O-1										
Cimarron										
Boise	0.34			4 Wells	1.57	26	63	226	324	
Texas										
Guymon	0.90			8 Wells	4.94	8	77	239	331	
Hooker	0.10			4 Wells	1.20	34	135	308	457	
Texhoma	0.88			3 Wells	0.18	14	48	208	318	
Beaver										
Beaver	0.30			3 Wells	0.94	55	51	234	413	
Harper										
Buffalo	0.30			Wells & Springs	0.30	43	72	276	453	
Laverne	0.30			3 Wells	1.40	52	114	350	556	
TOTAL	3.12				10.93					
Oklahoma										
O-2a										
Ellis										
Shattuck	0.28			5 Wells	1.60	12	11	230	296	
Woodward										
Woodward	1.20			36 Wells	5.20	26	23	107	197	
Devey										
Blaine										
Geary	0.14			5 Wells	2.00	64	200	350	783	
O'Keene	0.18			3 Wells	0.54	46	59	240	449	
Watonga	0.60			6 Wells	3.00	25	74	302	462	
TOTAL	2.40				12.34					
Oklahoma										
O-2b										
Roger Mills										
Cheyenne	0.08			4 Wells	0.22	6	11	230	350	
Custer										
Clinton	1.20	Lake Clinton	1.00	20 Wells	2.20	11	10	172	251	
Thomas	0.08			6 Wells	0.18	26	183	350	618	
Weatherford	0.40			15 Wells	1.50	3	6	116	179	
Beckham										
Elk City	0.90			16 Wells	2.60	38	118	328	519	
Erick	0.05			6 Wells	1.00	38	413	656	994	
Sayre	0.50			12 Wells	2.59	14	192	430	591	
Washita										
Cordell	0.55	Lake Cordell	0.30	15 Wells	1.60	10	7	129	187	
Sentinel	0.10			5 Wells	0.54	35	224	488	740	
Harmon										
Hollis	0.50			3 Wells & 2 Springs	0.58	14	54	250	410	

State Subarea County Municipality	Present Average Demand (mgd)	Water Supply Quantity				Water Supply Quality (ppm)			
		Surface Water		Ground Water		Cl ⁻	SO ₄ ⁼	Hardness (as CaCO ₃)	TDS
		Source	Yield (mgd)	Source	Yield (mgd)				
Oklahoma									
0-2b (Continued)									
Greer				13 Wells	1.19	20	16	142	265
Mangum	0.70			4 Wells	0.37	12	20	210	360
Granite	0.10								
Elk									
Elbow	0.68	Lake Hobart	2.30	11 Wells		16	57	208	306
Snyder	0.25	Lake Snyder	0.50	5 Wells		6	17	51	90
Mountain View	0.10			10 Wells	0.25	11	17	228	341
TOTAL	8.20		4.10		14.82				
Oklahoma									
0-3									
Moore				18 Wells	3.25	8	11	134	197
Alva	1.00			7 Wells	1.45	17	35	216	335
Waynoka	0.20								
Alfalfa				7 Wells	4.50	86	63	312	515
Cherokee	0.75								
Grant				7 Wells	1.40	76	76	313	688
Madford	0.17								
Major				5 Wells	1.44	17	16	209	283
Fairview	0.32								
TOTAL	3.44				12.04				
Oklahoma									
0-4									
Garfield				84 Wells	14.50	60	26	182	379
Enid	3.80								
TOTAL	3.80				14.50				
Oklahoma									
0-5									
Key									
Ponca City	8.00	Lake Ponca	15.00	74 Wells	26.65	32	30	180	268
Tonkawa	0.20			12 Wells	1.00	16	216	423	644
Newkirk	0.35	Lake Newkirk	0.30	4 Wells		8	36	134	181
Blackwell	2.50	Lake Blackwell							
		Chikaskia R.	3.00			37	108	256	402
TOTAL	11.05		18.30		27.65				
Oklahoma									
0-6									
Owage									
Pawhuska	1.25	Lake Pawhuska	3.25			5	13	133	156
Hominy	0.30	Lake Hominy	0.22			7	8	116	154
Fairfax	0.29	Lake Fairfax	1.00			5	13	137	183
Barnsdall	0.17	Lake Barnsdall	3.50			22	21	147	213
Creek									
Sapulpa	0.90	3 Impoundments	2.00			31	50	98	181
Oilton	0.02			9 Wells	0.03	135	91	318	653
Drumright	0.45			11 Wells	1.50	8	63	208	300
Bristow	0.25			19 Wells	0.82	54	44	314	457
Washington									
Dewey	0.78	Caneey P.	0.50			114	30	264	504
Bartlesville	3.00	Lake Hudson							
		Lake Hulah	15.00			9	20	69	105
Tulsa									
Skiatook		Tulsa							
Sand Springs	1.00	Shell Cr. Lake	3.00			22	22	56	117
Jenks	0.10			2 Wells	0.20	33	58	317	410
Gallinsville	0.18	Caneey R.							
		Morasshoe Lake	1.30			122	38	280	538
Broken Arrow	0.43			10 Wells	0.75	8	4	41	119
Bixby	0.15			4 Wells	0.29	18	5	53	135
Tulsa	32.80	Lake Spavinaw	100.00						
		Grand R.	32.00			5	6	91	114
TOTAL	41.88		156.77		3.59				
Oklahoma									
0-7									
Hoble									
Perry	0.60	Lake Perry	1.80						

Table B-1 (Continued)

EXHIBIT B-8

Municipal Water Supply Data

State Subarea County Municipality	Present Average Demand (mgd)	Water Supply Quantity				Water Supply Quality (ppm)			
		Surface Water		Ground Water		Cl ⁻	SO ₄ ⁼	Hardness (as CaCO ₃)	TDS
		Source	Yield (mgd)	Source	Yield (mgd)				
Oklahoma									
0-7 (Continued)									
Kingfisher				4 Wells	4.32	66	87	272	543
Kingfisher	0.20			4 Wells	0.35	250	25	424	825
Hennessey	0.20								
Logan									
Guthrie	0.80	Lake Liberty				15	18	199	231
		Lake Guthrie	2.25						
Crescent	0.15			3 Wells		112	54	400	642
Payne									
Yale	0.10			5 Wells	0.40	28	27	213	321
Stillwater	2.80	Lake Carl Black- Well, Lake Boomer	10.00			39	26	112	197
		Lake Cushing	2.98	9 Wells	1.31	24	11	124	175
Cushing	2.00								
Lincoln									
Stroud	0.17			9 Wells	0.39				
Prague	0.15			8 Wells	0.26	11	29	12	409
Chandler	0.15	Lake Chandler	0.83			20	32	552	612
TOTAL	7.88		19.44		7.23				
Oklahoma									
0-8									
Canadian									
El Reno	1.30			14 Wells	7.60	115	188	127	534
Yukon	0.16			6 Wells	5.58	66	138	505	807
Oklahoma									
Oklahoma City	30.12	N. Canadian R.	46.00	105 Wells	31.00	73	64	90	262
Edmond	1.00			10 Wells	4.00	150	68	82	712
Del City	1.00			12 Wells	1.50	8	6	192	230
Bethany	0.90			7 Wells	4.20	28	91	264	416
Midwest City	1.70			23 Wells	5.00	6	7	110	200
Nichols Hills	1.50			18 Wells	4.00	50	65	20	642
Warr Acres		Oklahoma City							
Village		Oklahoma City							
Cleveland									
Norman	1.80			20 Wells	3.80	13	96	8	550
Lexington	0.07			1 Well	0.36	42	84	398	574
Moore	0.06			2 Wells	0.25	7	6	222	279
TOTAL	39.81		46.00		67.29				
Oklahoma									
0-9									
McClain									
Purcell	0.48	Purcell Lake	0.86e	13 Wells		61	136	531	726
Blanchard	0.10			13 Wells	0.13	14	28	384	434
Caddo									
Anadarko	0.75	Washita R.		5 Wells	2.30	64	348	488	806
Apache	0.06			6 Wells	0.54	7	12	254	296
Carnegie	0.13			10 Wells	0.87	9	25	279	379
Cement	0.10			5 Wells	0.24	1,160	201	1,290	3,160
Cyril	0.13			6 Wells	0.28	11	78	300	407
Hinton	0.06			4 Wells	0.20	16	13	192	347
Grady									
Rush Springs	0.20			2 Wells	1.30	23	77	288	407
Minco	0.10			3 Wells	0.43	3	15	220	272
Chickasha	1.50	Washita R. (imp.)	5.50e			79	529	748	1,180
Garvin									
Wynnewood	0.25			10 Wells	0.88	147	166	476	1,040
Lindsay	0.32			9 Wells	1.90	25	130	621	723
Maysville	0.15			5 Wells	0.72	38	69	590	731
Pauls Valley	0.90	Washington Cr. & Lake Pauls Valley	2.83e	5 Wells	Standby	76	136	824	976
Stephens									
Marlow	0.25			18 Wells	1.30	127	84	266	522
Duncan	2.00	Duncan & Chisholm Trail Lakes	3.00			6	102	222	280
		Lake Comanche	0.44e			8	3	104	137
Comanche	0.20								
Sulphur	0.75			6 Wells	1.86	5	16	330	344
Davis	0.17			5 Wells	0.33	82	38	388	646
TOTAL	8.60		12.63		13.28				

Table B-1 (Continued)

EXHIBIT B-9

Municipal Water Supply Data

State Subarea County Municipality	Present Average Demand (mgd)	Water Supply Quantity				Water Supply Quality (ppm)			
		Surface Water		Ground Water		Cl ⁻	SO ₄ ⁼	Hardness (as CaCO ₃)	TDS
		Source	Yield (mgd)	Source	Yield (mgd)				
Oklahoma									
0-10									
Comanche									
Lawton	9.00	Lakes Lawtonka & Elmer Thomas	11.00			10	19	144	175
Cache	0.05			2 Wells	0.18e	7	21	97	161
TOTAL	9.05		11.00		0.18				
Oklahoma									
0-11									
Jackson	3.06	Lake Lugert	7.00e			215	522	606	1,230
Altus	0.05			4 Wells	0.18	109	949	1,260	1,840
El Dorado									
TOTAL	3.11		7.00		0.18				
Oklahoma									
0-12									
Tillman				2 Wells	0.24	148	93	316	748
Tipton	0.13			22 Wells	0.60	7	12	184	252
Grandfield	0.13			16 Wells	2.00	69	52	214	536
Frederick	0.60								
Cotton									
Temple	0.16	Cache Cr.		9 Wells	0.20	84	65	326	672
Walters	0.28	Boyer Res.	1.65	4 Wells	0.29	96	117	379	930
Jefferson									
Waurika	0.27			21 Wells	0.55	170	77	364	902
Ryan	0.13			17 Wells	0.46	52	58	448	631
Ringling	0.09			3 Wells	0.13	18	66	3	675
Love									
Marietta	0.11			2 Wells	0.43	13	45	48	427
TOTAL	1.90		1.65		4.90				
Oklahoma									
0-13									
Carter				3 Wells		21	111	214	524
Wilson	0.09			6 Wells	0.48e	139	15	12	1,060
Healdton	0.18								
Ardmore	3.50	Mountain and City Lakes	6.00e	8 Wells		8	22	148	181
TOTAL	3.77		6.00		0.48				
Oklahoma									
0-14									
Coal				5 Wells	0.17	32	36	6	386
Coalgate	0.13			5 Wells		70	256	304	644
Lehigh	0.04								
Pontotoc				1 Well	0.09	505	24	16	1,600
Allen	0.08			1 Spring	6.60	5	8	362	357
Ada	4.00								
Pottawatomie									
Tecumseh	0.25	Lake Tecumseh	0.50e			9	11	66	97
Shawnee	2.00	Shawnee Res.	10.00			11	25	74	108
Seminole									
Wewoka	0.75	Wewoka Lake	0.80			8	3	41	46
Seminole	1.00			19 Wells	2.00	4	47	124	244
Maud	0.25			5 Wells		136	372	16	1,640
Konowa	0.20			3 Wells	2.00	81	57	498	676
Okfuskee									
Wleetka	0.08	Grassy Lake	0.36e			9	10	37	91
Okemah	0.36			2 Wells	1.00	250	35	434	830
Boley	0.05			3 Wells	0.10	12	8	221	263
McIntosh									
Eufaula	0.23			2 Wells	0.72e	9	20	189	246
Checotah	0.20	Lake Checotah	1.10e			2	13	39	62
Hughes									
Wetumka	0.12	Lake Wetumka	0.25e			9	14	59	108
Holdenville	0.70	Holdenville Lake	4.00			4	9	47	68
TOTAL	10.44		17.01		12.68				

Table B-1 (Continued)

EXHIBIT B-10

State	Subarea	County	Municipality	Present Average Demand (mgd)	Municipal Water Supply Data				Water Supply Quality (ppm)			
					Water Supply Quantity				Hardness			
					Surface Water		Ground Water		(as CaCO ₃)			
					Source	Yield (mgd)	Source	Yield (mgd)	Cl ⁻	SO ₄ ²⁻	TDS	
<u>Oklahoma</u>												
0-15												
	Okmulgee			3.00	Salt Cr. & Lake				56	12	63	166
	Okmulgee				Okmulgee	7.00			13	81	83	182
	Morris			0.13	Morris Lake	0.25e			7	39	67	99
	Henryetta			1.00	Henryetta Lake & Wolfe Cr.	3.00			75	16	66	219
	Devar				Henryetta							
	Beggs			0.13	Beggs Lake	0.25e						
	Muskogee			8.00	Ft. Gibson Res.	50.00			48	12	88	137
	Muskogee			0.05			27 Wells	0.10e	9	3	40	133
	Baskett			0.19	Grand R.	0.50e			15	55	167	228
	Ft. Gibson			0.04	Boynton Lake	0.14e			14	63	66	179
	Boynton											
	TOTAL			12.54		61.14		0.10				
<u>Oklahoma</u>												
0-16												
	Nowata				Verdigris R.	4.00			172	58	351	664
	Nowata			0.36								
	Craig				Neosho R. & Grand Lake	4.50e			12	58	170	227
	Vinita			1.20								
	Rogers				Lake Claremore	1.34			4	17	50	115
	Claremore			0.61	Chelisea Lake	0.16e			3	45	121	156
	Chelisea			0.13								
	Mays				Grand R. Dam				11	55	166	223
	Fryor											
	Wagoner				Ft. Gibson Res.	1.50e			12	54	164	221
	Wagoner			0.50	Lake	0.10	7 Wells		8	4	47	97
	Coweta			0.07								
	TOTAL			2.87		11.60						
<u>Oklahoma</u>												
0-17												
	Cherokee				Illinois R.	1.50e			6	5	87	115
	Tahlequah			0.80								
	Adair						Springs	0.86	6	4	120	147
	Stillwell			0.40								
	Delaware				Grand Lake	0.29e			12	55	170	226
	Grove			0.07	Brush Cr.	0.21e			9	3	138	182
	Jay			0.12								
	Ottawa						Well	0.50	4	18	130	152
	Quapaw			0.20			3 Wells	0.52	16	16	130	170
	Picher			0.23			6 Wells	4.32	42	15	135	217
	Miami			1.20			2 Wells	0.50	8	16	123	159
	Commerce			0.30			2 Wells	1.08	348	18	172	758
	Afton			0.08								
	TOTAL			3.40		2.00		7.78				
<u>Oklahoma</u>												
0-18												
	Pittsburg				Lake McAlester	7.00			5	28	45	74
	McAlester			2.00	Quinton Lake	0.14e			10	8	19	59
	Quinton			0.10	Krebs Lake				2	5	18	33
	Krebs			0.15	Lake Hartshorne	1.00e			3	4	37	45
	Hartshorne			0.33	Hartshorne							
	Haileyville											
	TOTAL			2.58		8.14						
<u>Oklahoma</u>												
0-19a												
	Sequoyah				Vian Lake	0.12e			3	8	22	44
	Vian			0.08	Big Sallisaw Cr.	0.20			4	10	70	90
	Sallisaw			0.15	Pond	0.25e			7	66	37	153
	Muldrow			0.05								

Table B-1 (Continued)

EXHIBIT B-11

Municipal Water Supply Data

State	Subarea	County	Municipality	Present Average Demand (mgd)	Water Supply Quantity				Water Supply Quality (ppm)				
					Surface Water		Ground Water		Cl ⁻	SO ₄ ⁼	Hardness (as CaCO ₃)	TDS	
					Source	Yield (mgd)	Source	Yield (mgd)					
Oklahoma	0-19a (Continued)												
	Haskell		Stigler	0.26	Lake Stigler	1.44e	Wells		5	6	19		43
	Latimer		Wilburton	0.35	Cumneo Tubby Cr. Fourche Malins Cr.	0.80e			9	9	20		62
	LeFlore		Talihina	0.16	Lake Talihina	0.50e			7	7	18		52
	Spiro			0.35	Lake Spiro	0.46e	4 Wells		9	20	41		100
	Poteau			0.37	Poteau R.	2.10e			6	8	37		73
	Heavener			0.25	Black Fork Cr.	0.40e			6	5	14		41
	Panama			0.10	Poteau R.	0.11e			16	224	150		623
	Arkoma				Fort Smith, Ark.								
	TOTAL			2.12		6.38							
Oklahoma	0-19b												
	Pushmataha		Antlers	0.16	Kiamichi R.	0.15			6	7	17		65
	Choctaw			0.50			6 Wells	2.00e	5	22	252		312
	Hugo			0.05			3 Wells	0.07	83	70	394		621
	Boswell												
	McCurtain			0.50	Little R.	0.45			9	4	21		67
	Idabel			0.03	Broken Bow Res.	165.00			3	2	44		64
	Broken Bow												
	TOTAL			1.24		165.60		2.07					
Oklahoma	0-20												
	Johnston		Tishomingo	0.40	Pennington Lake	2.50e	Spring		4	4	258		248
	Marshall		Madill	0.20	Carter Lake & Madill City Lake	0.40			6	5	73		100
	Atoka		Atoka	0.50	Atoka & Katy Lakes	0.50			24	26	116		189
	Bryan			1.60	Blue R.	5.00			10	55	267		312
	Durant			0.05			4 Wells	0.08	20	32	2		503
	Caddo												
	TOTAL			2.75		8.40		0.08					
Texas	T-1												
	Oldham												
	Hartley												
	Dallam		Dalhart	0.80			8 Wells	4.00	13	44	214		327
	Sherman		Stratford	0.30			3 Wells	1.23	14	44	213		304
	Moore			1.10			8 Wells	5.02	9	29	204		267
	Dumas			0.28			2 Wells	2.10	14	25	210		275
	Sunray												
	Hansford		Spearman	0.50			4 Wells	2.80e	15	47	225		313
	Ochiltree		Perryton	1.20			6 Wells	5.18e	52	36	235		380
	TOTAL			4.18				20.33					
Texas	T-2												
	Potter		Amarillo	17.10			90 Wells	70.00	13	34	244		364
	Randall		Amarillo (See Potter Co.) Canyon	1.00			10 Wells	5.00	35	35	112		413
	TOTAL			18.10				75.00					

Table B-1 (Continued)

EXHIBIT B-12

State Subarea County Municipality		Present Average Demand (mgd)	Municipal Water Supply Data				Water Supply Quality (ppm)			
			Water Supply Quantity		Ground Water		Hardness			
			Surface Water	Yield (mgd)	Source	Yield (mgd)	Cl ⁻	SO ₄ ⁼	(as CaCO ₃)	TDS
<u>Texas</u> T-3										
	Hutchinson				15 Wells	16.20	17	97	202	330
	Borger	2.20			Well	0.90	10	27	238	280
	Stinnet	0.50								
	Carson				3 Wells		13	16	190	285
	White Deer	0.21			12 Wells	1.20	21	26	244	360
	Panhandle	0.23								
	Gray				3 Wells	1.10	25	18	213	308
	McLean	0.50			15 Wells	13.00e	82	101	227	532
	Pampa	6.00								
	TOTAL	9.64				32.40				
<u>Texas</u> T-4a										
	Lipscomb									
	Roberts									
	Hemphill				5 Wells	1.30	100	34	246	495
	Canadian	0.78								
	TOTAL	0.78				1.30				
<u>Texas</u> T-4b										
	Wheeler				Springs	5.00	20	63	254	366
	Shamrock	1.20								
	Armstrong				4 Wells		14	28	250	354
	Claude	0.10								
	Donley				Wells	2.00e	25	21	263	351
	Clarendon	0.50								
	Collingsworth				6 Wells	0.72	36	108	310	530
	Wellington	0.25								
	Briscoe				4 Wells	0.79	14	18	278	339
	Silverton	0.15								
	Hall				25 Wells	1.20	16	18	225	304
	Memphis	0.30								
	Childress				14 Wells	1.00	40	306	378	481
	Childress	1.10	Lake Childress	2.00						
	TOTAL	3.60		2.00		10.71				
<u>Texas</u> T-5										
	Deaf Smith				9 Wells	7.78	28	170	390	574
	Hereford	1.80								
	Farmer				2 Wells	0.81				
	Bovina	0.31			Wells	1.65	31	30	221	288
	Friona	0.44			2 Wells	0.90	16	27	172	276
	Farwell	0.21								
	Castro				4 Wells	2.60				
	Dimmit	0.75								
	Swisher				6 Wells	2.90e	26	25	208	363
	Tulia	0.88								
	Floyd				4 Wells	2.50	36	57	257	430
	Floydada	0.50			Wells	1.80	36	36	250	461
	Lockney	0.33								
	TOTAL	5.22				20.94				
<u>Texas</u> T-6										
	Hale				2 Wells	1.50e	18	26	237	345
	Hale Center	0.25			9 Wells	10.30	24	30	252	366
	Plainview	4.00			5 Wells	3.30	34	24	260	384
	Abernathy	0.41								
	TOTAL	4.66				15.10				
<u>Texas</u> T-7										
	Motley				4 Wells	0.50	167	139	395	1,042
	Matador	0.23								
	Cottle				9 Wells	0.70	23	151	305	463
	Paducah	0.21								

Table B-1 (Continued)

EXHIBIT B-13

Municipal Water Supply Data

State Subarea County Municipality	Present Average Demand (mgd)	Water Supply Quantity				Water Supply Quality (ppm)			
		Surface Water		Ground Water		Cl ⁻	SO ₄ ⁼	Hardness (as CaCO ₃)	TDS
		Source	Yield (mgd)	Source	Yield (mgd)				
Texas									
T-7 (Continued)									
Hardeman				5 Wells		11	28	213	295
Chillicothe	0.20			11 Wells	2.30	132	315	550	892
Quannah	0.60								
Wilbarger				38 Wells	2.60	24	28	248	342
Vernon	1.30								
Foard				8 Wells	0.70	29	131	320	450
Crowell	0.20								
Dickens				Wells	1.50	302	476	550	1,566
Spur	0.31								
King									
Knox				3 Wells	1.30	395	400	40	1,950
Munday	0.40			Well	1.00	205	211	490	1,212
Knox City	0.30								
Baylor				12 Wells	2.50e	79	76	309	551
Seymour	0.45								
Stonewall				3 Wells	0.40	53	71	250	564
Aspermont	0.18								
Haskell				4 Wells	0.76	67	46	295	540
Rule	0.21			18 Wells	2.10	160	126	365	912
Haskell	1.00					44	18	150	241
Throckmorton	0.15	Lake Throckmorton	0.50						
TOTAL	5.74		0.50		16.36				
Texas									
T-8									
Wichita						18	29	263	468
Electra	0.18	China Cr.				152	159	277	637
Iowa Park	0.20	Lake Iowa	1.20			46	40	274	465
Burkburnett	0.50			48 Wells	1.40				
Wichita Falls	11.50	Lake Wichita & Holliday Cr.	22.00			29	16	100	183
TOTAL	12.38		23.20		1.40				
Texas									
T-9									
Archer						25	48	133	297
Archer City	0.20	Impounded Lake	0.54e			56	41	198	321
Holliday	0.04	Impounded Lake	0.25e						
Clay						227	23	161	600
Henrietta	0.25	Lake Wichita	0.65e						
Young						11	28	108	248
New Castle	0.04	Lake	0.03			122	13	124	352
Olney	0.53	Lake	1.50e			42	14	62	139
Graham	1.08	Reservoir	2.50e						
Jack				Wells	0.75e	22	26	196	250
Jacksboro	0.29								
TOTAL	2.43		5.47		0.75				
Texas									
T-10									
Montague						17	20	103	160
Bowie	0.40	Lake Amon Carter	2.80			14	37	8	436
Nocona	0.30			13 Wells	0.60	153	56	137	740
Saint Jo	0.10			3 Wells	0.24				
Wise				8 Wells	0.61	44	24	58	387
Decatur	0.30					18	71	154	230
Bridgeport	0.23	W. Fork Trinity	0.58e						
Parker						8	16	133	178
Weatherford	0.95	Impounded Lake	4.50e						
TOTAL	2.28		7.88		1.45				
Texas									
T-11									
Cooke				8 Wells	3.50	45	34	8	513
Gainesville	2.00			3 Wells	0.25	19	39	10	420
Muenster	0.12								

Table B-1 (Continued)

EXHIBIT B-14

Municipal Water Supply Data										
State	Subarea	Present Average Demand	Water Supply Quantity				Water Supply Quality (ppm)			
County	Municipality	(mgd)	Surface Water		Ground Water		Cl ⁻	SO ₄ ²⁻	Hardness (as CaCO ₃)	TDS
			Source	Yield (mgd)	Source	Yield (mgd)				
Texas										
T-11 (Continued)										
Grayson					Wells		80	39	9	581
Whitesboro					2 Wells		32	76	4	546
Van Alstyne					2 Wells	0.39e	64	111	111	762
Whitewright	0.11		Red R., Shawnee Cr., Lake Texoma	8.00e						
Denison	3.50									
Sherman	4.00				12 Wells	8.60	169	115	144	507
							136	86	9	776
TOTAL	9.73			8.00		12.74				
Texas										
T-12										
Denton					4 Wells	0.25	11	68	5	592
Sanger	0.10		Lewisville Res.	4.00	3 Wells	0.14	21	89	7	550
Pilot Point	0.18				11 Wells	10.00	45	31	65	177
Denton	3.00				3 Wells	0.45	143	210	56	1,335
Lewisville	0.16									
Collin					2 Wells		32	58	7	596
Celina										
Tarrant										
Fort Worth	46.00	W. Fork Trinity	57.00				22	20	139	208
Arlington	3.85	Lake Arlington	4.00		12 Wells	5.00	20	32	42	132
Grapevine	0.27				3 Wells	0.55	145	221	15	1,152
White Settlement	0.77				14 Wells		13	48	210	364
Lake Worth	0.13				3 Wells	0.23	48	150	9	798
River Oaks	0.78	Lake Worth	1.99e				23	19	140	205
Sansom Park	0.18					7 Wells	0.50	14	60	7
Westworth					Wells					
Halton City	2.00					4.00	103	160	11	960
Hurst	0.40				4 Wells	0.55	22	88	7	606
N. Richland Hills					Wells					
Richland Hills	1.40				9 Wells	2.80	85	128	9	780
Dallas										
Irving	1.50	Dallas			8 Wells		100	170	24	868
Grand Prairie		Dallas			8 Wells	9.00	85	169	51	870
Lancaster					3 Wells	1.80	177	228	19	1,200
Seagoville		Dallas Aux.			2 Wells	0.70				
Richardson		Dallas Aux.			2 Wells	1.10	59	100	54	336
Carrollton		Dallas Aux.			3 Wells		134	115	13	981
Dallas		5 Lakes	124.00		Wells	15.00	42	46	79	
Cockrell Hill		Dallas								
Farmers Branch		Dallas Aux.			Well	0.13e	212	465	16	1,640
Duncanville					3 Wells		86	169	11	930
WCID #2 (University Park & Highland Park)			Grapevine Lake	13.50						
WCID #6 (Malch Springs)				0.11	2 Wells	1.10	302	356	28	1,526
WCID #7 (Kleberg)					Well	0.90	278	175	20	1,410
Johnson										
Alvarado					2 Wells		38	195	16	864
Cleburne					9 Wells		43	88	8	580
Burleson					3 Wells	0.43	26	100	7	652
Keene					2 Wells		21	60	31	550
Ellis										
Italy					2 Wells	0.53	110	493		1,500
Midlothian					3 Wells	1.00	71	75	12	688
Ennis					3 Wells		147	72	365	843
Ferris					2 Wells		145	359	12	1,617
Waxahachie		Lake Waxahachie	3.00		4 Wells		9	20	110	144
NTMWD										
(Collin Co. - Plano, Farmersville, McKinney, Wylie Dallas Co. - Mesquite, Garland)	13.00	Lake Lavon	44.00				14	48	160	256
TOTAL	73.72			251.60		56.16				
Texas										
T-13										
Fannin					2 Wells	0.62	147	214	10	924
Honey Grove	0.25				Well		1,633	189	303	3,710
Ladonia					2 Wells	0.59e	61	190	8	840
Leonard					3 Wells	2.44e	118	195	5	1,050
Bonham	0.80									

Table B-1 (Continued)

EXHIBIT B-15

Municipal Water Supply Data

State Subarea County Municipality	Present Average Demand (mgd)	Water Supply Quantity				Water Supply Quality (ppm)			
		Surface Water		Ground Water		Cl ⁻	SO ₄ ⁼	Hardness (as CaCO ₃)	TDS
		Source	Yield (mgd)	Source	Yield (mgd)				
Texas									
T-13 (Continued)									
Lamar Paris	2.42	Pine Cr.	6.00			13	54	100	145
Delta Cooper	0.15	Cedar Cr. (Imp.)	0.36e			4	33	31	64
TOTAL	3.62		6.36		3.65				
Texas									
T-14									
Hopkins Sulphur Springs	0.86	White Oak Bayou & Lakes	5.00			11	31	55	81
Hunt Commerce	0.50			6 Wells		74	106	6	672
Wolfe City	0.15	Reservoir (Imp.)	0.28e			6	10	58	94
Greenville	2.50	Sabine R.	6.00e			14	28	100	150
Rockwall Royse City	0.09	NTMWD				10	39	70	145
Rockwall	0.05	NTMWD				53	215	17	956
Kaufman Terrell	1.07	Lake NTMWD		7 Wells	2.00e	11	54	96	159
Forney						15	44	64	141
Kaufman	0.25	City & Kaufman Lake	0.35e			5	6	84	129
TOTAL	5.47		11.63		2.00				
Texas									
T-15									
Wood Winnsboro				Springs & Wells	1.28e	10	12	74	104
Mineola	0.40			3 Wells	1.98	13	21	29	180
Quitman	0.15			2 Wells	1.40e	15	101	102	270
Rains Emory	0.03			Well		80	288	390	630
Van Zandt Grand Saline	0.20	Lake (Imp.)	0.75e			225	11	14	690
Wills Point	0.30	Lake (Imp.)	1.00e			11	30	64	105
Canton	0.15			Well	0.30	22	26	97	200
Van	0.14	Lake (Imp.)	0.43e			57	65	90	243
TOTAL	1.37		2.18		4.96				
Texas									
T-16									
Red River Clarksville	0.40			2 Wells	2.00e	167	137	8	1,071
Bogata	0.06			2 Wells	0.25e	34	2	21	123
Franklin Mount Vernon	0.15	Mount Vernon Lake	0.36e			24	57	100	178
Titus Mount Pleasant	0.80	Lakes (Imp.)	1.00			36	23	80	146
Talco				Well		360	4	10	960
Morris Daingerfield	0.35			4 Wells	1.00e	13	34	59	131
Naples	1.20			3 Wells	0.16	47	6	8	395
Lone Star	0.10	Reservoir	1.29e	Wells		32	49	77	156
Camp Pittsburg	0.50			Wells	0.80	37	36	20	360
TOTAL	3.56		2.65		4.21				
Texas									
T-17									
Bowie DeKalb	0.13			5 Wells	0.34	46	49	58	211
Texarkana	2.30	Lake Texarkana Lake Bringle	6.50	42 Wells		27	53	85	188
New Boston	0.35			Spring	0.72e	4	33	55	97
Hooke Wake Village	0.11	Lake		7 Wells	1.08e	191	1	61	450
Cass Atlanta	0.50			Wells	1.84	96	9	9	513
Linden	0.10			2 Wells		74	7	156	263
Hughes Springs				4 Wells	0.26	6	26	55	146
Queen City				4 Wells					
TOTAL	3.49		6.50		4.24				

Table B-1 (Continued)

EXHIBIT B-16

Municipal Water Supply Data

State Subarea County Municipality	Present Average Demand (mgd)	Water Supply Quality				Water Supply Quality (ppm)			
		Surface Water		Ground Water		Cl ⁻	SO ₄ ⁼⁼	Hardness (as CaCO ₃)	TDS
		Source	Yield (mgd)	Source	Yield (mgd)				
Texas									
T-18									
Marion Jefferson	0.38			2 Wells	0.65e	296	5	7	1,080
Upshur Gilmer	0.40			4 Wells	2.00	22	47	14	311
Gregg Longview	3.50	Big Sandy Cr.	55.00			27	13	44	102
Gladeview	0.73	Lake Gladeview	2.00e			31	16	37	99
Kilgore	1.50			5 Wells	4.80e	16	25	27	171
White Oak				Well		240	15	23	714
Harrison Marshall Waskom	2.50	Cypress Bayou	3.00	Wells		35	32	63	146
						161	79	73	899
TOTAL	9.01		60.00		7.45				
Texas									
T-19									
Rusk Henderson Overton	1.00 0.30			7 Wells 3 Wells	4.00 0.43e	16 21	16 67	9 45	300 322
Fanola Carthage	0.40			4 Wells	1.00e	35	11	30	267
TOTAL	1.70				5.43				
Missouri									
M-1									
Jasper Joplin (part) Carthage Carterville Webb City Sarcoxis Carl Junction	6.40 1.10 0.20 1.00 0.07 0.09	Shoal Cr. Webb City	30.00	6 Wells 3 Wells 2 Wells 2 Wells	2.80 0.74 0.72 0.43	8 37	10 57	131 107	167 246
Newton Granby Neosho Seneca Joplin (part)	0.05 0.30 0.08	Shoal Cr.	8.30	1 Well 5 Wells Wells	0.35 (Standby) 0.36				
TOTAL	9.29		38.30		5.40				
Missouri									
M-2									
Barton Lamar	0.25	Impoundment	66.00						
Dade Greenfield	0.09			2 Wells	0.26				
Lawrence Aurora Mount Vernon Marionville Monett (part) Pierce City	0.50 0.30 0.12 0.08			3 Wells 3 Wells 1 Well Wells Well	1.44 1.40 0.25 0.86				
Stone Barry Cassville Monett (part)	 0.22 0.50			1 Well 6 Wells	0.51 2.90				
McDonald		Impoundment	0.58						
TOTAL	2.06		66.58		7.62				
Arkansas									
A-1									
Benton Bentonville Siloam Springs Rogers	0.90 0.70 0.70	Lake Francis Lake Atlanta	10.00 3.00	Springs Spring	2.00	10 9 14	8 12 8	122 118 127	180 168 175
Washington Springdale Fayetteville Prairie Grove	1.00 2.23 0.05	Osage Cr. W. Fork White R.	7.00 3.50	Spring Springs & Wells	 0.34	9 6	12 11	147 67	161 91
TOTAL	5.60		23.50		2.34				

Table B-1 (Continued)

EXHIBIT B-17

State Subarea County Municipality	Present Average Demand (mgd)	Municipal Water Supply Data				Water Supply Quality (ppm)			
		Water Supply Quantity							
		Surface Water		Ground Water					
		Source	Yield (mgd)	Source	Yield (mgd)	Cl ⁻	SO ₄ ⁼⁼	Hardness (as CaCO ₃)	TDS
<u>Arkansas</u>									
A-2									
Carroll									
Berryville	0.22			Springs	0.55	6	33	113	161
Eureka Springs	0.12	Leatherwood Cr. (Imp.)	0.72e			4	13	99	169
Green Forest	0.11			Spring	0.36	8	8	233	249
Boone									
Harrison	0.85			Spring	2.00e	2	0	168	194
Madison									
Huntsville	0.06	War Eagle Cr.	0.29e			5	28	83	121
Newton									
Searcy									
Marshall	0.06			Well & Spring	0.12e	5	10	210	246
TOTAL	1.42		1.01		3.03				
<u>Arkansas</u>									
A-3									
Crawford									
Van Buren	0.50	Fort Smith Lee Cr.				15	42	76	143
Mulberry	0.10	Big Mulberry Cr.	0.26e			4	38	55	102
Franklin									
Ozark	0.20			5 Wells	0.58e	6	8	48	134
Charleston	0.06	Charleston Lake	0.36e			7	11	39	72
Johnson									
Coal Hill				Wells					
Clarksville	0.55			Wells	4.00	3	0	31	56
Pope									
Atkins	0.20			3 Wells	0.40e	8	7	151	225
Russellville	1.00	Illinois Bayou	1.52e			4	5	20	33
Logan									
Paris	0.36	Short Mountain Cr. (Imp.)	0.72e			7	23	40	54
Booneville	0.20	Parker, Fletcher, & City Lakes	0.50e			6	31	51	76
Scott									
Waldron	0.22	Square Rock Cr. (Imp.)	0.36e			9	17	41	86
Yell									
Dardanelle	0.20			3 Wells	0.50	73	23	139	345
Perry									
Conway									
Morrilton	0.50			4 Wells	1.75	25	20	136	219
Van Buren									
Cleburne									
Heber Spring	0.14	Little Red R.	0.28e			3	11	35	45
Faulkner									
Conway City	0.95	Cadron Cr. (Imp.)	2.00			3	11	21	50
TOTAL	5.18		6.00		7.23				
<u>Arkansas</u>									
A-4									
Sebastian									
Fort Smith	5.60	Lake Fort Smith	15.00e	Spring		3	8	31	20
Hartford	0.06			2 Wells	.06e	34	106	46	565
Huntington				Wells					
Greenwood	0.20	Vacne Grasse Vineyard Cr.	0.36			16	42	41	160
TOTAL	5.86		15.36		.06				
<u>Arkansas</u>									
A-5									
Polk									
Mena	0.33	Lake Ward	0.69e			5	18	43	79
Montgomery									
Hot Springs									
Malvern	0.90	Ouachita	25.00			8	10	39	74
Clark									
Arkadelphia	0.70	Ouachita	48.00						
Gurdon	0.16			4 Wells	0.40e	158	40	10	347

Table B-1 (Continued)

EXHIBIT B-18

Municipal Water Supply Data

State	Subarea	County	Municipality	Present Average Demand (mgd)	Water Supply Quantity				Water Supply Quality (ppm)			
					Surface Water		Ground Water		Cl ⁻	SO ₄ ⁼	Hardness (as CaCO ₃)	TDS
					Source	Yield (mgd)	Source	Yield (mgd)				
Arkansas												
A-5 (Continued)												
	Saline	Benton	0.80	Saline R. & Brushy Cr.	6.00			4	3	36	100	
	Bauxite		0.25	Saline R.	5.00			10	20	77	110	
	Reynolds Metals			Hurricane Cr. Res.								
	TOTAL		3.14		84.69		0.40					
Arkansas												
A-6												
	Garland	Hot Springs	2.89	Lake Hot Springs	14.00			7	6	36	41	
	TOTAL		2.89		14.00							
Arkansas												
A-7												
	Pulaski	Little Rock	17.40	Lake Winona	21.00			4	0	28.6	47	
				Lake Maumelle	83.00			22	0	73	145	
	Jacksonville		1.40			11 Wells	2.25					
	N. Little Rock			Little Rock								
	Sherwood			Little Rock								
	Commack			Little Rock								
	Jefferson											
	Pine Bluff		3.40			7 Wells	12.20	2.2	2	24	93	
	West End					Wells						
	Pine Bluff					Wells						
	Southwest											
	TOTAL		22.20		104.00		14.45					
Arkansas												
A-8												
	White											
	Beebe		0.10			Well	0.40	81	7	51	329	
	Judsonia			Searcy				3	7	29	76	
	Searcy		0.20	Little Red R.	2.00e			3	15	32	77	
	Bald Knob			Searcy								
	Lonoke											
	Lonoke		0.20			2 Wells	0.36e	8	3	118	196	
	England		0.17			2 Wells	0.40e	34	20	248	376	
	Carlisle		0.12			2 Wells	0.20e	21	15	154	244	
	Cabot		0.08			2 Wells	0.47e	5	0	23	85	
	Arkansas											
	DeWitt		0.25			2 Wells	0.75e	10	0	47	199	
	Stuttgart		0.75			4 Wells	2.00e	21	12	82	197	
	Monroe											
	Clarendon		0.07			2 Wells	1.00e	67	0	81	394	
	Brinkley		0.40			2 Wells	1.50e	117	80	154	455	
	Prairie											
	Des Arc		0.08			Well	0.50e	24	0	226	306	
	Hazen		0.06			2 Wells	0.18e	14	5	222	330	
	TOTAL		2.48		2.00		7.76					
Arkansas												
A-9												
	Lafayette											
	Stamps		0.23			2 Wells	1.50	7	5	39	130	
	Buckner		0.02			Well	0.14	11	0	83	124	
	Bradley		0.02			Well		137	0	28	658	
	Lewisville		0.15			2 Wells	0.50	11	3	65	133	
	Sevier											
	Horatio		0.04			2 Wells	0.23e	0	1	58	50	
	DeQueen		0.30			6 Wells	1.30	8	1	95	225	
	Howard											
	Nashville		0.35	Lake Nichols	0.32			15	10	50	118	
	Dierks		0.06	Lake Dierks				8	1	11	39	
	Pike											
	Glenwood		0.10	Caddo R.	0.28e			8	8	53	81	
	Murfreesboro		0.06			Well	0.18e	1	2	10	34	

Table B-1 (Continued)

EXHIBIT B-19

Municipal Water Supply Data									
State	Present	Water Supply Quantity				Water Supply Quality (ppm)			
Subarea	Average	Surface Water		Ground Water		Hardness			
County	Demand	Source	Yield (mgd)	Source	Yield (mgd)	Cl ⁻	SO ₄ ⁼	(as CaCO ₃)	TDS
Municipality	(mgd)								
Arkansas									
A-9 (Continued)									
Little River									
New Rocky				Wells					
Comfort	0.10e			5 Wells	0.50	32	12	180	319
Ashdown	0.15								
Hempstead									
Hope	0.90			6 Wells	2.00	118	46	25	637
Miller									
Texarkana	3.80			23 Wells	1.20	16	24	61	158
TOTAL	6.28		0.60		7.55				
Arkansas									
A-10									
Nevada									
Prescott	0.74			4 Wells	0.50	126	68	111	663
Columbia									
Taylor	0.04			Well		8	1	30	89
Waldo	0.15			3 Wells	0.20e	23	2	37	396
McNeil	0.10			Well		8	11	144	250
Magnolia	0.80			4 Wells	0.50	9	11	16	234
Emerson	0.02			Well		3	0	20	151
TOTAL	1.85				1.20				
Arkansas									
A-11									
Ouachita		Ouachita R.	130.00			7	12	40	76
Camden	1.00								
Stephens	0.07			3 Wells	0.50e	5	6	33	130
Bearden	0.07			2 Wells	0.70e	11	7	48	155
Union									
El Dorado	2.53			8 Wells	18.00	31	0	4	278
Junction City	0.05			2 Wells		41	1	3	217
Huttig	0.11			Wells		216	0	6	689
Morphlet	0.04			Wells		34	0	4	313
Smackover	0.23			4 Wells		18	0	8	267
TOTAL	4.10		130.00		19.20				
Arkansas									
A-12									
Grant									
Sheridan	0.20			2 Wells	1.00	6	6	30	78
Dallas									
Fordyce	0.20			2 Wells		7	8	79	193
Cleveland									
Calhoun									
Hampton	0.04			3 Wells		11	10	6	231
Bradley									
Warren	0.58			3 Wells	2.00	6	3	12	218
TOTAL	1.02				3.00				
Arkansas									
A-13									
Lincoln									
Star City	0.16			Well & 13 Springs	0.30e	3	0	33	110
Gould	0.10			Well	0.35e	5	3	4	150
Desha									
Dumas	0.23			2 Wells		10	1	2	142
Arkansas City	0.05			2 Wells	0.65	15	3	3	215
McGehee	0.25			Wells		7	1	3	207
Drew									
Monticello	0.85			2 Wells		5	0	4	140
Ashley									
Hamburg	0.11			2 Wells	0.84e	70	12	209	409
Crossett	0.40			3 Wells	28.00	120	11	135	480

Table B-1 (Continued)

EXHIBIT B-20

Municipal Water Supply Data									
State	Present Average Demand (mgd)	Water Supply Quantity				Water Supply Quality (ppm)			
Subarea		Surface Water		Ground Water		Cl ⁻	SO ₄ ²⁻	Hardness (as CaCO ₃)	TDS
County		Source	Yield (mgd)	Source	Yield (mgd)				
Municipality									
Arkansas									
A-13 (Continued)									
Chicot									
Eudora	0.20			2 Wells	0.60e	42	0	81	225
Lake Village	0.13			2 Wells		275	2	53	823
Dermott				2 Wells		15	1	4	225
TOTAL	2.50				30.74				
Louisiana									
L-1									
Caddo									
Shreveport	22.40	Cross Lake & 12 Mile Bayou	53.00			41	33	68	162
Vivian	0.35			3 Wells	1.00				
N. Shreveport	0.70	Shreveport							
Oil City	0.12	Caddo Lake							
Bossier									
Bossier City	3.00	Red R.							
Benton	0.01			3 Wells	0.40				
Plain Dealing	0.09			2 Wells					
Haughton	0.06			Well					
Webster									
Cotton Valley	0.08			2 Wells	0.36				
Spring Hill	0.32	Lake Erling	30.00	5 Wells	3.00				
Dayline	0.70			Well					
Minden	1.00			5 Wells	4.90				
Sibley				Wells					
Cullen	0.20			2 Wells					
TOTAL	29.03		83.00		9.66				
Louisiana									
L-2									
Claiborne									
Homer	0.50			6 Wells					
Haynesville	0.35			3 Wells	1.50				
Union									
Farmerville	0.30			2 Wells					
Bernice	0.10			2 Wells					
Lincoln									
Ruston	1.50			6 Wells		8	13	6	198
Grambling				Well					
Dubach	0.08			2 Wells					
Bienville									
Gibbsland	0.07			3 Wells					
Arcadia	0.25			3 Wells					
Red River									
Coushatta	0.18			3 Wells					
De Soto									
Mansfield	0.65			6 Wells					
Logansport	0.25			4 Wells					
Jackson									
Jonesboro	0.50			3 Wells					
Hodge	0.33			Wells	1.50				
Winn									
Winnfield	0.75			4 Wells	1.76				
Caldwell									
Clarke	0.07			2 Wells	0.72				
Columbia	0.18			2 Wells					
Grant									
Colfax	0.13			2 Wells	0.13				
La Salle									
Jena	0.25			4 Wells	1.89				
Urania	0.05			2 Wells					
Olla	0.08			3 Wells					
TOTAL	6.57				7.50				
Louisiana									
L-3									
Ouachita									
Monroe	6.00	Bayou Desired	6.00			16	16	36	75
		Ouachita R.	1,000.00			19	0	2	299
W. Monroe	0.80			4 Wells					
Brownsville				2 Wells					
Splane Place				Wells					

Municipal Water Supply Data

State Subarea County Municipality	Present Average Demand (mgd)	Water Supply Quantity				Water Supply Quality (ppm)			
		Surface Water		Ground Water		Cl ⁻	SO ₄ ⁼	Hardness (as CaCO ₃)	TDS
		Source	Yield (mgd)	Source	Yield (mgd)				
Louisiana									
L-3 (Continued)									
Morehouse									
Bastrop	1.25	Bayou Bartholomew	30.00	Wells	12.00	186	2	6	697
TOTAL	8.05		1,036.00		12.00				
Louisiana									
L-4									
West Carroll				2 Wells	1.20				
Oak Grove	0.17								
East Carroll				3 Wells	2.88				
Lake Providence	0.35								
Richland									
Delhi	0.15	Bayou Mason		2 Wells					
Rayville	0.40								
Madison				2 Wells					
Tallulah	0.50								
Franklin				3 Wells	2.76				
Winnsboro	0.30			2 Wells					
Wisner	0.06								
Texas				Wells					
Waterproof	0.10			Wells					
St. Joseph	0.10			2 Wells	0.76				
Hewellton	0.17								
Catahoula				3 Wells					
Jonesboro	0.50								
Concordia				3 Wells					
Ferriday	0.30			Wells	1.08				
Vidalia	0.20								
Avoyelles				3 Wells					
Bunkie	0.40			2 Wells					
Cottontport	0.08			2 Wells					
Menauna	0.03			2 Wells					
Marksville	0.28			2 Wells					
Simmesport	0.15			2 Wells					
TOTAL	4.32				8.68				
Louisiana									
L-5									
Hatchitoches				12 Wells	2.00				
Hatchitoches	1.00			Wells					
Campiti	0.10								
TOTAL	1.10				2.00				
Louisiana									
L-6									
Rapides				21 Wells	8.16	28	17	213	476
Alexandria	5.00			2 Wells					
Lecompte	0.20			3 Wells					
Glenmora				6 Wells					
Pineville	0.43			Alexandria					
Alexandria S.W.				Wells					
Anandale				Wells					
Samtown				2 Wells					
Cheneyville	0.15			2 Wells					
Boyce									
Pineville Junction		Rapides Parish W. D.							
		No. 1							
Wardville				Wells					
TOTAL	5.78				8.16				

Future

Future municipal water demands for use in computing annual project benefits are projected to the year 2020. These projections are developed by multiplying the projected municipal population by a 2020 unit use factor in gallons per capita per day (gpcd).

Available water use data were collected for the period 1950-1960 from 44 municipalities throughout the study area. Cities not metered or having rationed water were excluded in order to form a more realistic projection base. Although longer term records are desirable, data previous to 1950 are not used because many cities had poor records, or none at all.

Municipal per capita requirement figures are calculated by subtracting any major industrial use (see Exhibit C) from the total water use and dividing the adjusted use by the estimated population served. Table B-2 summarizes historic per capita water use data thus developed for the 44 cities.

To learn if variations noted in per capita use are associated with any of the usually investigated criteria, comparisons are attempted with municipal population-size group, population density, personal income, price of water, rainfall, climate factor, aridity factor, distance from a single isohyetal line and combinations of some of these variables. Of the factors investigated, only ones pertaining to climate displayed a noticeable relationship. These factors all indicated that the water demand generally increased as the climate became dryer. Of the four factors pertaining to climate, rainfall data are more readily available, therefore, it is chosen for further investigation.

As noted in Table B-2 most cities had an abnormally high per capita demand in 1956. To determine the significance of this, historic precipitation data are assembled for 16 study area cities, including 13 of the 15 SMSA's (major municipal water demand centers). Data for these cities, representing all portions of the study area, are assembled in Table B-3.

Table B-2^{1/}Historic Per Capita Water Use

Municipality	Year										
	'50	'51	'52	'53	'54	'55	'56	'57	'58	'59	'60
Colo. Springs, Colo.	236	225	264	254	204	241	264	189	218	231	261
Pueblo, Colo.	352	337	334	337	306	262	260	249	260	250	236
Great Bend, Kans.	109	121	142	145	129	161	128	86	89	113	107
Hutchinson, Kans.	92	93	120	132	142	122	150	132	130	93	87
Wichita, Kans.	138	144	161	154	155	136	135	117	107	110	97
Coffeyville, Kans.	---	---	---	---	128	143	138	133	81	87	118
Parsons, Kans.	116	108	156	135	118	92	94	74	72	---	---
Pittsburg, Kans.	---	88	93	97	105	90	102	106	99	102	110
Altus, Okla.	---	---	---	---	---	149	162	138	145	145	146
Lawton, Okla.	---	---	---	---	---	---	146	134	140	137	139
Enid, Okla.	---	---	123	105	106	98	126	105	103	98	88
Duncan, Okla.	---	74	86	94	120	95	112	100	87	88	---
Ponca City, Okla.	---	102	114	104	115	110	124	105	105	102	100
Okla. City, Okla.	89	83	95	99	86	100	97	96	93	92	---
Norman, Okla.	83	87	89	95	101	88	102	93	95	87	---
Stillwater, Okla.	109	102	105	103	124	122	124	109	112	110	108
Tulsa, Okla.	108	105	102	105	104	110	118	102	106	111	---
Muskogee, Okla.	129	118	116	118	138	127	137	118	129	146	164
Okmulgee, Okla.	113	118	139	143	154	154	146	138	153	143	146
McAlester, Okla.	81	104	108	115	116	101	120	116	115	133	---
Amarillo, Texas	---	---	---	---	---	---	171	---	169	---	144
Plainview, Texas	165	167	188	224	226	169	211	162	166	181	---
Borger, Texas	---	---	83	91	98	99	125	100	84	101	94
Pampa, Texas	85	102	120	136	145	118	154	117	112	119	---
Wichita Falls, Tex.	129	166	177	142	139	134	156	119	120	139	128
Fort Worth, Texas	95	112	127	122	131	126	140	129	125	126	---
Sherman, Texas	80	86	97	89	92	98	109	91	98	95	---
Dallas, Texas	121	127	139	127	147	140	161	141	140	145	140
Paris, Texas	88	94	95	102	112	120	131	115	117	114	---
Longview, Texas	---	---	---	---	---	---	124	96	95	104	---
Marshall, Texas	104	105	107	118	129	124	129	123	120	128	---
Joplin, Mo.	124	132	139	139	147	142	154	162	162	165	167
Neosho, Mo.	---	---	---	---	---	139	132	91	123	121	115
Van Buren, Ark.	---	---	85	71	65	62	71	66	70	67	75
Fort Smith, Ark.	117	127	117	115	115	87	90	105	119	125	121
Fayetteville, Ark.	72	81	83	82	82	69	98	81	80	68	---
Hot Springs, Ark.	---	---	---	---	---	88	92	92	96	101	115
Little Rock, Ark.	81	91	101	111	114	98	102	99	110	99	105
Pine Bluff, Ark.	---	---	---	---	---	87	82	79	84	95	93
Crossett, Ark.	55	68	66	71	69	69	70	67	68	73	---
Shreveport, La.	103	118	120	124	125	117	133	114	116	103	112
Alexandria, La.	80	92	113	106	113	96	106	102	131	111	109
Monroe, La.	130	138	129	128	135	127	136	124	127	113	---
Bastrop, La.	58	67	64	63	62	56	56	58	56	59	---

Table B-32/

Summary of Precipitation Records

Weather Station	Years of Record	Annual Precipitation (in.)				No. of Yrs. Precip. <1956
		Mean	Min.	(Year)	1956	
Pueblo, Colorado	57	11.50	5.78	(1934)	6.66	2
Raton, New Mexico	54	16.11	8.02	(1956)	8.02	0
Amarillo, Texas	57	20.77	9.94	(1956)	9.94	0
Dodge City, Kansas	57	20.07	9.97	(1956)	9.97	0
Lubbock, Texas	51	16.84	8.73	(1917)	10.83	3
Colo. Springs, Colo.	57	14.59	6.07	(1939)	10.93	6
Wichita, Kansas	57	30.12	12.73	(1956)	12.73	0
Fort Worth, Texas	57	31.51	17.91	(1921)	18.55	2
Wichita Falls, Texas	38	26.34	16.36	(1952)	21.31	6
Dallas, Texas	49	34.66	21.45	(1956)	21.45	0
Oklahoma City, Okla.	57	31.93	17.27	(1910)	22.56	6
Tulsa, Oklahoma	57	37.47	23.24	(1956)	23.24	0
Fort Smith, Arkansas	52	50.19	19.80	(1917)	30.68	6
Texarkana, Arkansas	51	49.07	23.39	(1936)	31.44	2
Shreveport, Louisiana	57	44.93	26.33	(1918)	34.01	6
Little Rock, Arkansas	52	48.09	31.57	(1924)	32.34	37

In eleven of the above listed stations, the lowest annual precipitation fell in 1956 since 1936 and at six of the stations it was the year of least annual precipitation of record. Exceptions to the "generally dry" classification of 1956 occurred in some portions of the eastern study area. Little Rock, for instance, had slightly greater than mean precipitation during the year. These areas of exception are few, however, and apparently of limited serial extent since the lowest annual runoff ever recorded on the Arkansas River at Little Rock, and the Red River at Shreveport, occurred during the calendar year 1956.^{2/}

With regard to the series of dry years in the mid-1950's, the Weather Bureau states that 1952-1956 drought has not generally been matched in severity since the latter part of the 19th century, and has not been exceeded in most study area States since the beginning of reliable records. Return period of the 1952-1956 drought are of the order of 40 years in Texas, Colorado, and New Mexico; and roughly 140 years in Oklahoma and Kansas.^{2/}

On the above basis, 1956 is selected as a base for designing "dry year" demands because it was generally dry throughout most of the study area and reliable water use data representing recent conditions are readily available. Table B-4 demonstrates the relationship between 1956 gpcd and precipitation at various municipalities throughout the study area.

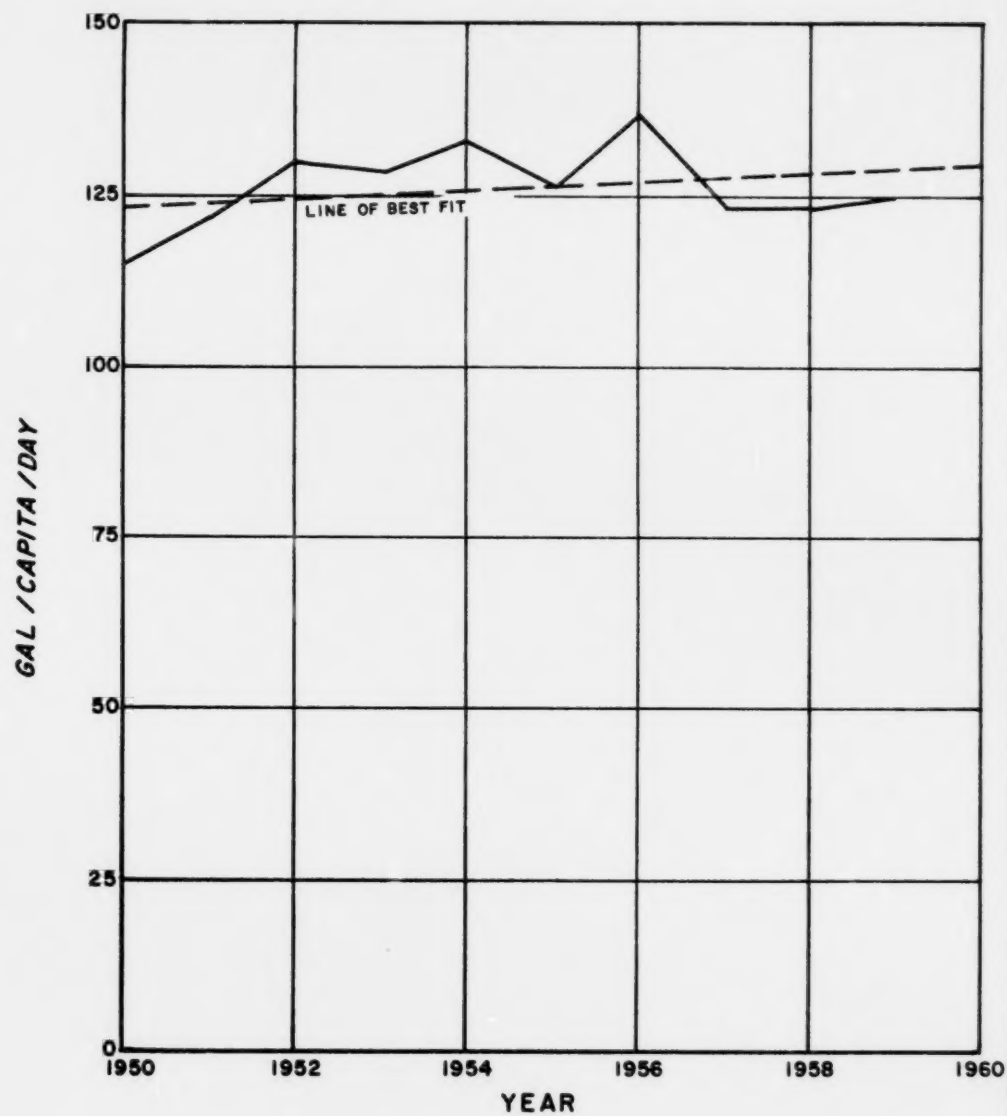
With increasing use of such appliances as automatic clothes washers, dish washers, and garbage disposals, as well as the advent of the backyard swimming pool, and well watered yards, an increase in domestic water use has been noted with the passage of time. To determine if such an increase prevailed in the study area, historic per capita use data in all communities for which ten years of record is available are averaged. Weighted per capita demands for the years 1950 through 1959 indicated an average annual increase of 0.62 gpcd per year existed in these 27 cities. (See Figure B-1.) Assuming the same rate of increase would pertain for the next 60 years, an increase of 37 gpcd could be expected in the year 2020.

It is assumed that in the year 2020, cities in the study area will have similar water use characteristics. Therefore, to obtain a per capita base for projection, present "dry year" conditions are normalized. This is done by averaging the gpcd's of cities with similar traits in the same precipitation belt. The previously calculated 37 gpcd increase is then added to the present normalized demand to obtain the gpcd figures for 2020. Some example municipalities are presented in Table B-5. The appropriate projected rates rounded to the nearest 5 gpcd are multiplied by the projected municipal population to obtain the 2020 municipal water demand for each subarea.

Table B-4

1956 Precipitation vs. GPCD

<u>Municipality</u>	<u>Precipitation (in.)</u>	<u>GPCD</u>
Plainview, Texas	9	211
Amarillo, Texas	10	171
Pampa, Texas	11	154
Borger, Texas	12	125
Enid, Oklahoma	13	126
Wichita, Kansas	13	135
Great Bend, Kansas	14	128
Hutchinson, Kansas	14	150
Colo. Springs, Colo.	14	264
Stillwater, Okla.	14	124
Ponca City, Okla.	15	124
Altus, Oklahoma	18	162
Fort Worth, Texas	19	140
Okmulgee, Oklahoma	19	146
Wichita Falls, Texas	21	156
Norman, Oklahoma	21	102
Lawton, Oklahoma	21	146
Okla. City, Okla.	23	97
Tulsa, Oklahoma	23	118
Sherman, Texas	23	109
Coffeyville, Kansas	24	138
Parsons, Kansas	24	94
Muskogee, Oklahoma	27	137
McAlester, Okla.	27	120
Paris, Texas	29	131
Marshall, Texas	30	129
Neosho, Missouri	30	132
Van Buren, Arkansas	31	71
Fort Smith, Arkansas	31	90
Tarkenton, Tex. & Ark.	31	98
Joplin, Missouri	32	154
Longview, Texas	33	124
Shreveport, Louisiana	34	133
Alexandria, Louisiana	46	106
Bastrop, Louisiana	47	69
Monroe, Louisiana	48	136
Pine Bluff, Arkansas	48	82
Little Rock, Arkansas	52	102
Hot Springs, Arkansas	55	92



ARKANSAS-RED RIVER BASINS
WATER QUALITY CONSERVATION PROJECT-
BENEFITS EVALUATION

MUNICIPAL WATER USE TRENDS

DEPARTMENT OF HEALTH, EDUCATION, & WELFARE
PUBLIC HEALTH SERVICE
REGION VII DALLAS, TEXAS

FIGURE B-1

Table B-5

Municipal Water Demand Projections

<u>Municipality</u>	<u>Dry Year</u>		
	<u>Expected Precipitation (inches)</u>	<u>Normalized Demand</u>	
		<u>Present (gpcd)</u>	<u>2020 (gpcd)</u>
Amarillo, Texas	10	161	200
Wichita, Kansas	13	157	190
Altus, Oklahoma	18	147	185
Tulsa, Oklahoma	23	137	175
Paris, Texas	29	130	165
Texarkana, Texas	31	121	155
Fayetteville, Ark.	39	112	145
Ruston, Louisiana	43	100	135
Little Rock, Ark.	50	88	125

Bibliography - Exhibit B

1. Municipal water use data, personal contact with local Water Department personnel.
2. U.S. Department of Commerce, Weather Bureau, Local Climatological Data with Comparative Data, Washington, Government Printing Office, 1961.
3. U.S. Department of the Interior, Water Supply Paper 1311 and other published and unpublished records of the Geological Survey. Washington, Government Printing Office.
4. U.S. Department of Commerce, Weather Bureau, Weekly Weather and Crop Bulletin, Special Weather Summary, "National Summary for Drought," Washington, Government Printing Office, January 10, 1957. Vol. XLIV, No. 1a.

Industrial Water Demands

Industrial water use is that which is a function of the size and type of industrial plant and the conservation measures practiced by the plant. It is not directly related to the population of the area in which the industry is located, but is more nearly expressed as the number of gallons per unit of product than any other measure.

The necessity for making a separate projection of industrial water will depend on its magnitude in relation to the total water demand. This may vary from a negligible quantity in a large urban area with diversified industry to several times the municipal component when there is a predominance of the so-called "wet" industries. The "wet" or principal water using industries include those described in Senate Select Committee Print No. 8¹/₂ and thermal electric power plants. Of these, the following industries are expected to exert significant demands in the Ark-Red basin during the next 60 years.

1. Thermal Power Generation
2. Petroleum Refining
3. Petrochemical
4. Natural Gas Processing
5. Pulp and Paper
6. Primary Metals (iron, steel, aluminum)
7. Food and Kindred

The methodologies employed in projecting water demands for each follow and a summary is presented in a Table at the conclusion of this Exhibit.

Thermal Power Generation

Thermal power generation is the largest water user in industry. In 1959, approximately 70 percent of the total industrial water was used within this industry.^{1 2 3} This, however, is the total water requirement and not consumptive use as developed in this report. Table C-1 provides comparative data on water requirements for thermopower generation in the Nation.

Consumptive use of water for thermal power can be defined as that portion of the total water required which is lost to evaporation. This water is referred to as condensing or circulating water. (The amount lost in the boiler make-up requirement is excluded.) If the water is taken from a lake or stream, it is returned to its source with little, if any, change in quality.

TABLE C-1

EXHIBIT C-2

WATER REQUIREMENTS OF ELECTRIC UTILITY STEAM-ELECTRIC GENERATING PLANTS - 1959
SUPPLY, RECIRCULATION, AND LOSSES

GEOGRAPHIC AREA	TOTAL GENERATION KWH (Thousands)	% COV- ERAGE	MILLIONS OF GALLONS							TOTAL USE IN GALLONS PER KWH
			WATER SUPPLY			RECIRCULATION	TOTAL USE	LOSSES	DISCHARGED	
			FRESH	BRACKISH	TOTAL					
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)
NEW ENGLAND	21,683,278	95.58	201,135	1,190,225	1,391,358	49,198	1,440,556	1,790	1,389,568	66.44
Maine	838,979	83.83	52	35,514	35,566	867	36,433	23	35,543	43.42
New Hampshire	1,168,653	99.31	43	50,903	50,946	1,244	52,190	29	50,917	44.65
Vermont	36,390	97.08	6,146	6,146	6,146	55	6,201	106	6,040	170.40
Massachusetts	11,004,423	95.74	83,621	464,290	547,911	33,868	581,779	1,011	546,900	52.87
Rhode Island	1,464,547	92.30	332	137,271	137,603	5,087	142,690		137,603	97.43
Connecticut	7,170,286	97.03	110,941	502,245	613,186	8,077	621,263	621	612,565	86.65
MIDDLE ATLANTIC	93,713,247	99.63	3,400,758	2,762,760	6,163,518	164,886	6,328,404	10,990	6,152,528	67.53
New York	37,744,586	99.81	980,050	1,888,585	2,868,635	36,443	2,905,078	5,637	2,862,998	76.97
New Jersey	17,202,794	99.64	226,095	874,175	1,100,270	38,574	1,138,844	3,264	1,097,006	66.20
Pennsylvania	38,765,867	99.45	2,194,613		2,194,613	89,869	2,284,482	2,089	2,192,524	58.93
EAST NORTH CENTRAL	151,182,612	98.27	8,679,022		8,679,022	309,619	8,988,641	7,361	8,671,661	59.46
Ohio	46,901,294	98.07	2,632,582		2,632,582	146,483	2,779,065	3,147	2,629,435	59.25
Indiana	28,601,045	98.56	1,525,302		1,525,302	37,860	1,563,162	1,509	1,523,793	54.65
Illinois	40,751,738	98.83	2,475,698		2,475,698	87,437	2,563,135	1,562	2,474,136	62.90
Michigan	23,970,020	98.10	1,348,575		1,348,575	28,957	1,375,532	869	1,347,706	57.38
Wisconsin	10,958,515	96.69	696,865		696,865	10,882	707,747	274	696,591	64.58
WEST NORTH CENTRAL	28,837,424	85.50	1,445,721		1,445,721	567,234	2,012,955	11,915	1,433,796	69.80
Minnesota	6,355,789	94.81	376,451		376,451	14,725	391,176	153	376,298	61.55
Iowa	5,562,141	87.22	340,905		340,905	112,195	453,100	4,782	336,123	81.46
Missouri	7,650,524	86.04	413,869		413,869	69,378	483,247	1,396	412,473	63.16
North Dakota	122,722	16.89	355		355	7,302	7,657	178	177	62.39
South Dakota	328,344	67.44	335		335	24,574	24,909	253	82	75.86
Nebraska	2,381,347	83.55	156,943		156,943	6,947	163,890	155	156,768	68.82
Kansas	6,436,157	92.25	156,863		156,863	332,113	488,376	4,998	151,855	75.97
SOUTH ATLANTIC	84,179,776	98.58	3,045,772	2,147,043	5,192,815	223,061	5,415,876	4,735	5,188,080	64.34
Delaware	2,220,858	98.84	647	162,548	163,195	3,206	166,401	550	162,645	74.92
Maryland	6,497,955	97.15	65,954	303,293	369,247	6,208	375,455	218	369,029	57.78
District of Col.	1,269,281	100.00	180,615		180,615	1,530	182,145	25	160,590	127.75
Virginia	16,371,218	98.92	572,315	330,050	902,365	134,719	1,037,084	2,154	900,211	63.35
West Virginia	13,533,099	100.00	710,598		710,598	11,276	721,874	195	710,403	53.34
North Carolina	14,010,865	98.14	567,875	46,785	614,660	23,555	638,215	572	614,088	45.55
South Carolina	6,017,647	98.52	255,131	43,332	298,463	7,966	306,429	537	297,926	50.92
Georgia	9,178,784	99.31	516,481	65,303	581,784	9,825	591,609	41	581,743	64.45
Florida	15,080,071	97.26	196,156	1,195,732	1,391,888	24,776	1,416,664	443	1,391,445	93.94
EAST SOUTH CENTRAL	65,825,630	99.22	2,906,699	95,762	3,002,461	308,142	3,310,603	5,354	2,997,107	50.29
Kentucky	16,619,506	98.77	798,774		798,774	59,886	858,660	728	798,046	51.67
Tennessee	29,531,146	99.94	1,290,417		1,290,417	29,611	1,320,028	269	1,290,148	44.70
Alabama	16,976,524	99.21	777,446	61,209	838,675	49,848	888,523	93	838,582	52.34
Mississippi	2,698,454	94.50	40,042	34,553	74,595	168,797	243,392	4,264	70,331	90.19
WEST SOUTH CENTRAL	54,742,920	97.62	790,102	529,546	1,319,648	2,263,297	3,582,945	31,191	1,288,457	65.45
Arkansas	4,379,764	99.68	77,685		77,685	180,137	257,822	2,121	75,564	58.87
Louisiana	9,959,455	96.75	235,061	90,256	325,317	152,007	517,324	6,475	318,842	51.94
Oklahoma	6,645,890	95.98	43,895	430	44,325	340,903	385,228	4,334	39,991	57.97
Texas	33,757,811	97.91	433,461	438,860	872,321	1,550,250	2,422,571	18,261	854,080	71.76
MOUNTAIN	14,117,085	93.38	102,628		102,628	789,917	892,545	9,392	93,236	63.22
Montana	156,281	72.87	6,655		6,655	178	6,833	3	6,652	43.72
Idaho										
Wyoming	651,843	89.59	19,369		19,369	5,439	24,808	164	19,205	38.05
Colorado	3,316,315	86.51	27,583		27,583	190,949	218,532	2,182	25,401	65.90
New Mexico	2,566,018	92.28	3,262		3,262	196,482	199,744	2,273	989	77.84
Arizona	4,560,924	99.49	26,011		26,011	228,426	254,437	3,105	22,906	55.78
Utah	2,362,268	95.50	19,110		19,110	146,201	165,311	1,344	17,766	69.98
Nevada	503,436	100.00	638		638	22,242	22,880	321	317	45.45
PACIFIC	40,401,826	99.54	8,107	1,623,010	1,631,117	627,274	2,258,391	6,405	1,624,722	55.90
Washington										
Oregon										
California	40,401,826	99.63	8,107	1,623,010	1,631,117	627,274	2,258,391	6,405	1,624,722	55.90
UNITED STATES TOTAL	554,683,798	97.68	20,579,944	8,348,344	28,928,288	5,302,628	34,230,916	89,133	28,839,155	61.71

EXHIBIT C-3

The Bureau of Business Research of the University of Texas conducted a study on circulating water requirements.^{3/} The results showed a range from 40 gallons per net kilowatt-hour generated in newer plants to around 100 gallons per kilowatt-hour for older plants. A study was also conducted on consumptive use of circulating water with plants using cooling tower or spray ponds.^{3/} These results show a range from 0.6 gallons per kilowatt-hour for newly installed plants to 1.2 gallons per kilowatt-hour for the older installations.

In order to estimate the consumptive use of water for thermal power generation, it was necessary to estimate the energy requirement per day. This was accomplished by projecting on the basis of a per capita kilowatt-hour consumption of electrical energy and a unit consumptive use of water per kilowatt-hour.

National projections to 1980 made by Edison Electric Institute and the Federal Power Commission for the Senate Select Committee were extrapolated to the year 2020.^{2/} This was done for a comparison to our study area. By utilizing their bases, we were able to project kilowatt-hour on a per capita basis. Beginning our curve for the year 1960 at the national average of 12.5 kilowatt-hour per capita per day, the final results for the year 2020 indicated a rate of 105 kilowatt-hours per capita for Edison Electric Institute and 34 kilowatt-hours per capita for Federal Power Commission. See Figure C-1.

Ebasco Services, Incorporated conducted a study on electric utility generating capacity.^{4/} The information was gathered from Edison Electric Institute, Federal Power Commission, large manufacturers, and Electric World. The projections were to the year 1980 with the following results.

Federal Power Commission	430 million kilowatts
Ebasco Services, Inc.	540 million kilowatts
Edison Electric Institute	570 million kilowatts
Electric World	630 million kilowatts
Large Manufacturers	700 million kilowatts

This study was also used as a guide to our projections in the Ark-Ped Benefit study area.

The Federal Power Commission's kilowatt-hour per capita predictions made for the U.S. Study Commission-Texas area were also plotted to indicate their thoughts that the energy requirements for this area exceed those for the country as a whole. The Nation shows a 1950-60 trend of 10 percent increase as compared to a 38 percent rise in this region. It is anticipated that the growth will continue at a high rate for the next 10- and possibly 20-year period and then progress at about the same rate as the Nation as a whole.

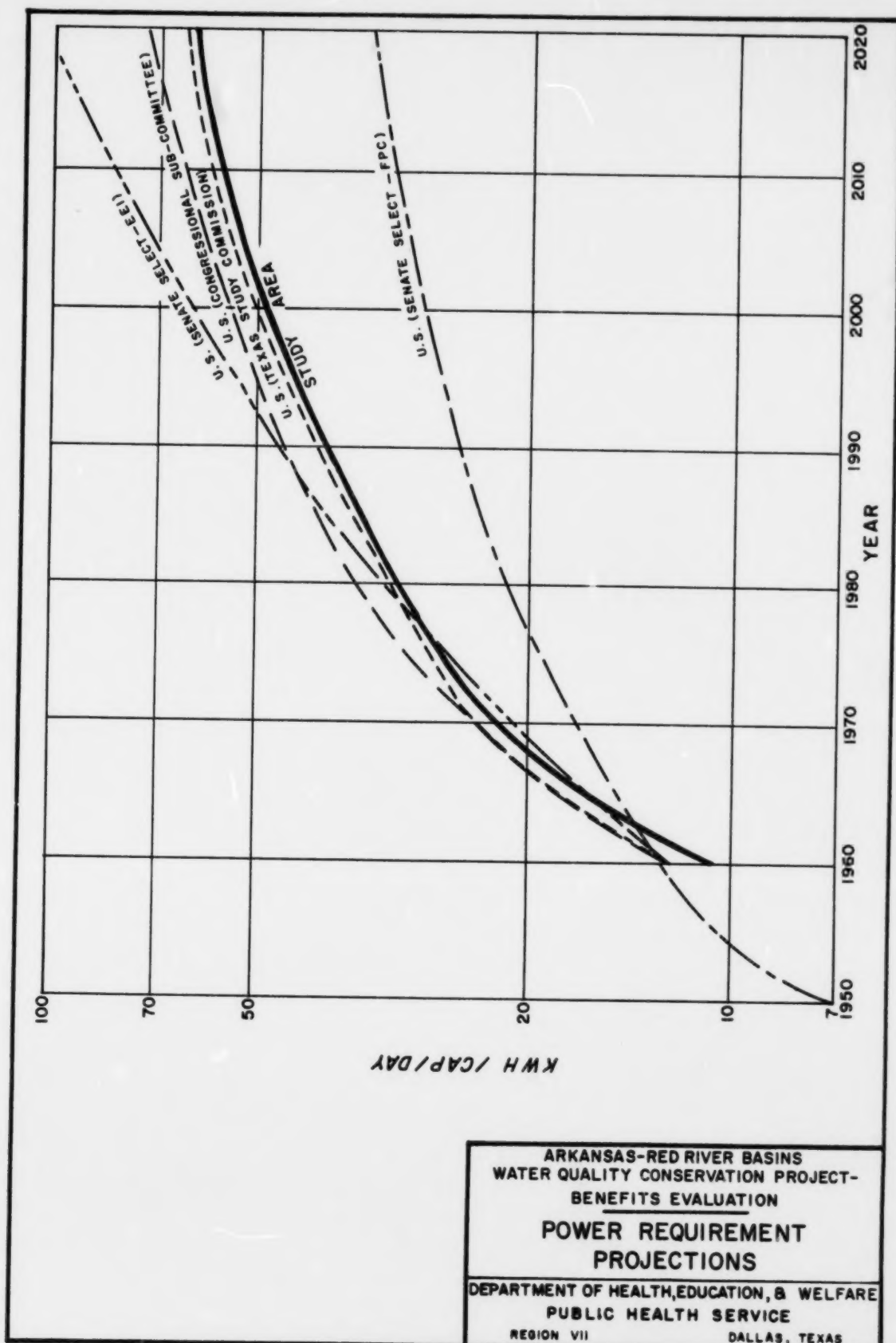


FIGURE C-1

EXHIBIT C-4

Historical trends would establish similar projections, with the Ark-Red Benefit Study below that of the U.S. Study Commission-Texas study area. This is due to the greater industrial area along the Gulf Coast. In the U.S. Study Commission-Texas report,^{3/} the Federal Power Commission's extrapolated figure for the year 2020 shows 63.5 kilowatt-hours per capita as against our study area's 62.7 kilowatt-hour per capita figure. See Table C-1.

Increased efficiency in power plants indicates a decrease in the needed gallons per kilowatt-hour. As stated previously and as reported by the Senate Select Committee, a drop from 1.2 gallons per kilowatt-hour to 0.6 gallons per kilowatt-hour should be noted in the newer installations.^{3/} In the year 2020 it was assumed that the average generating plant would require approximately the consumptive use found in the better plants of today. Therefore, a figure of 0.7 gallons per kilowatt-hour was selected for this study area for the year 2020.

The projected populations for each subarea for 2020 were then used as a basis for the consumptive water use. The population figures for each subarea multiplied by our projected kilowatt-hour per capita per day figure times the 0.7 gallons per kilowatt-hour selection gives the estimated consumptive water use.

Hydroelectric power is not of great significance in the subareas of the Ark-Red Benefit Study area, and it is assumed that all additional power requirements will be supplied by thermal power generation. Therefore, all power needs were assumed to be generated by thermoelectric plants and consumptive use figures developed accordingly.

Petroleum Refining

Present Industry in the Ark-Red Basins

The petroleum industry in the Arkansas and Red River Basins has been a significant factor in the growth of the area. In terms of value, crude petroleum was the principal mineral produced in the basins in 1960.^{2/} The value of national petroleum production to total value of all mineral production was about 57 percent for the same period. An idea of the proved recoverable petroleum reserves and refinery capacity in the basins with relation to national reserve and capacity is given in the following Table.

Table C-2^{6 7/}Petroleum Reserves and Refinery Capacity

Area	Oil Refineries		Capacity		Proved Recoverable Reserves	
	Number	% of	bbl/day	% of	Billion bbl.	% of
		Total		Total		Total
Ark-Red	46	15.4	957,860	9.6	6.4	16.8
(Eight States)*	118	41.0	4,355,097	43.8	28.0	73.8
Total U.S.	298	100.0	9,933,725	100.0	38.0	100.0

*Totally or partially within the basins.

Total U.S. petroleum production in 1960 amounted to about 2.9 billion barrels.^{8/} At this rate of production, the known recoverable U.S. reserves (38 billion bbl.) would be depleted in 13 years if new additions were not made to the present supply. The 13 year figure has also applied in past years indicating that the yearly increase in reserves has just been keeping pace with production. It is generally understood among oil experts^{9/} that sooner or later an oil producing area will go over the hump, so to speak, and will start a gradual fall in production with the constant drop off slowed to some extent by advanced methods of secondary recovery. Eventually the field will be nonproductive as many are today. (It is believed that many fields in the Ark-Red Region which have been producing for many years have done so.) For the petroleum industry to continue to grow and meet the demands of the Nation, new sources of crude must be found.

Source of Future Crude Oil Supply

Several possibilities exist for supplementing present crude oil supplies to meet future demands. They are:

1. New methods of secondary recovery may make possible nearly 100 percent recovery of the oil and gas potential of a field.^{9/} Such methods, if applicable to all types of oil producing formations, would double our present known recoverable reserves which are based on 50 percent recovery.
2. Development of oil shales in the Colorado River basin is expected to provide a major source of crude oil supply.^{10/} Known reserves of shale oil in the Rocky Mountain area have been estimated at about 900 billion barrels by the U.S. Geological Survey.

EXHIBIT C-6

3. Oil experts believe large reserves will be located with further exploration of the Continental Shelf area of Louisiana and California and the new State of Alaska.
4. By the year 2000 about 50 percent of the crude processed in this country may be imported from other areas of the world.^{1/}
5. Estimates of total economically recoverable petroleum and oil-shale resources of the United States and the free world are given in the following Table.^{10/}

Table C-3

Petroleum and Oil-Shale Resources

	(billions of barrels)	
	<u>Liquid Hydrocarbons</u>	<u>Shale Oil</u>
United States	170	2,000+
Rest of Free World	730	2,000+
TOTAL	900	4,000+

As local reserves in the Ark-Red basins are depleted, refineries may obtain crude from sources listed above. Crude from the Colorado River basin could be distributed throughout the basins through the vast system of oil and gas pipelines now established, and future lines. Crude petroleum may also be brought in by barge^{11/} from other regions.

Future Production in Ark-Red Basins

Current petroleum production in the study area is expected to increase by about 4.2 times from 758,000 bbl/day to 3,200,000 bbl/day to help meet the expected increase in the national demand for petroleum products in 2020.^{17 12/} The major oil refining centers in the study area are expected to remain essentially the same.

Petroleum Refining Water Demands

In projecting water demands for the petroleum refining industry, the following methodology is employed.

1. The projected petroleum refinery output in barrels of petroleum per day is multiplied by a unit water demand (1,722 GAL. OF WATER PER BARREL OF PETROLEUM REFINED)^{13/} to obtain a total once through (no recirculation) water demand.

2. The total demand was divided into a cooling water demand which ranges between 95 and 99 percent ^{14/} of the total once through demand and a miscellaneous water use demand which includes process water and sanitary water and ranges between 1 and 5 percent ^{14/} of the total once through demand. (For this report, an average of 97 percent and 3 percent are used for cooling and miscellaneous demand, respectively.)
3. The expected areas of refinery expansion were then investigated more thoroughly as to availability of water to determine the percent of the once through cooling water requirement which could be supplied by the area if recirculation were practiced. The percentage thus established is used to determine the total cooling water demand for each area.
4. The total projected water demand was then determined by adding the cooling water demand with the miscellaneous water demand.

The following assumptions are used:

1. Since large dependable supplies of water that might be used for cooling are scarce in the western half of the Arkansas-Red River basins (west of Wichita Falls, Texas, and Wichita, Kansas), it is assumed that large water using industries in this area will tend to obtain maximum use of available water. Generally, this would mean maximum recirculation of cooling water. The demand under these conditions would be about 5 percent ^{13 15/} of the once through cooling water requirement.
2. Principal water using industries in the eastern half of the basins will tend to approach the national average in recirculation. The average demand at present is about 27 percent of the once through cooling water requirement. ^{13/} With increased utilization of air cooling and improved heat transfer methods, the unit water demand is expected to decrease. ^{1 16/} The average for 2020 is estimated at about 20 percent of the once through cooling requirement.

Projected water demands to the year 2020 for the petroleum refining industry in the study area are given in Table C-4.

Table C-4

Projected Water Demands for the Petroleum Refining Industry

State	Sub-area	General Area of Expansion	Present Capacity BBL/Day ⁷	Approx.* 1960 Prod. BBL/Day ⁷	Proj. 2020 Prod. BBL/Day	Cooling Water			Water For Total	
						Once Thru Demand Per BBL of Prod. (Gal) 13 14/	Recirculation (2 of once thru)	Proj. Demand (mgd)	Other Purposes (mgd) 14/	Water Demand (mgd)
Texas	T-1	Sunday	25,000	20,000	76,300	1,670	5	7	4	11
	T-2	Amarillo	15,000	15,200	57,400	1,670	5	5	3	8
	T-3	Phillips	71,000	56,800	216,800	1,670	5	19	11	30
	T-8	Wichita Falls	20,800	16,700	63,600	1,670	5	6	3	9
	T-11	Gainesville	2,000	1,600	6,300	1,670	15	1	1	7
	T-12	Dallas-Ft. Worth	11,400	9,130	51,200	1,670	15	13	3	16
	T-16	Mt. Pleasant	19,000	15,200	80,000	1,670	15	22	5	27
	T-18	Longview	10,300	8,240	47,600	1,670	15	13	2	15
Okla.	O-4	Enid	31,680	25,300	95,300	1,670	5	8	5	13
	O-5	Ponca City	107,000	83,500	323,000	1,670	15	83	17	100
	O-6	Tulsa	124,000	99,200	375,000	1,670	15	97	19	116
	O-7	Cushing	36,920	29,500	121,000	1,670	10	16	5	21
	O-9	Duncan-Wynnewood	00,000	64,000	242,000	1,670	5	21	12	33
	O-12	Grandfield	7,200	5,760	22,100	1,670	5	2	1	7
	O-13	Armore	25,000	20,000	76,700	1,670	5	7	4	11
	O-15	Oklagee	19,000	13,200	86,000	1,670	15	22	5	27
Kan.	K-7	McPherson	31,000	24,800	92,500	1,670	5	8	5	13
	K-8	Wichita-El Dorado	153,250	122,500	465,000	1,670	5	40	24	64
	K-11	Neodesha	31,400	25,200	143,000	1,670	15	37	7	44
	K-12	Coffeyville	24,500	19,500	111,000	1,670	15	28	6	34
Ark.	A-11	El Dorado	80,400	64,300	360,000	1,670	20	123	19	142
La.	L-1	Shreveport	17,500	14,000	79,600	1,670	20	28	4	32
			947,440	757,630	3,195,090					

*Estimated 80 percent of capacity - the national average for 1960

Petrochemical

Background

Much of the past economic growth of the Arkansas and Red River basins and the Nation as well has been attributed to development of natural resources (petroleum and natural gas in particular). With the development of these resources and considerable progress in technological know-how spurred on by increased demands for new and better fibers, materials, detergents, fertilizers, fuels, etc., the petrochemical^{*} industry developed. Petrochemicals, which use as feedstock by-products from petroleum refineries and natural gas processing plants, were expected to account for about 30 percent of all chemical production in 1960.^{17/} This amounts to about 56 billion pounds. The value of these petrochemicals was expected to approach \$6.9 billion or 61 percent of the total value of all chemicals.

Criteria for Plant Location

The most favorable conditions for location of a petrochemical plant according to industry experts^{17/} are those such as afforded the Gulf Coast petrochemical complex which has been hailed as an "Industrial Cinderella" since about 85 percent of the U.S. industry is within 400 miles of New Orleans.^{18/} These conditions are:

1. Nearby a readily available supply of raw materials from refineries and gas fields.
2. A plentiful supply of cheap natural gas for fuel.
3. Ample supplies of salt. (Many of the major petrochemical producers have located their plant next to salt domes, a trend that is becoming more pronounced. There are 300 salt domes between southwestern Alabama and the lower tip of Texas. The industry is currently converting resources of the salt domes into a rapidly growing number of products.)^{18/}
4. Ample supplies of fresh water.
5. Ample supplies of sulfur and lime.

^{*}Petrochemicals - Chemical compounds or chemical elements recovered in whole or in part from petroleum or natural gas and intended as raw materials for the chemical processing industry.^{19 20/}

6. Ready access to water transportation for the plant products either by ocean going tanker or river barge (access to market).
7. Also, many of these plants are dependent on other plants for interchange of raw materials and by-products, so there tends to be a snowballing effect.

While all of the above conditions are not prevalent (to a significant degree) in any one area in the Arkansas-Red region, the basins are expected to supply their own demands for petrochemicals and be competitive to outside markets in some products. Large-scale productive units and combinations are expected to supply local and interior markets while small-scale plants are expected to supply chief agricultural areas with sufficient demands for fertilizers and insecticides.

Present Production in Ark-Red Basins

Petrochemical production in the Ark-Red basins in 1960 accounted for about 9 percent (approximately 5 billion pounds)^{17/} of the total U.S. production. That the industry has experienced a rapid growth in the basins is pointed up by the increase in number of plants from 2 to over 45 since 1940.^{17 21/}

Methodology used in Projecting Petrochemical Growth

To determine future growth of this industry in the basins, consideration was given to future national demands and that portion of the demand which might be satisfied by the petrochemical industry in the basins. The 2020 projected production for the basins is 38.7 billion pounds. This amounts to about 5 percent of the projected national production.

The following assumptions were made in regard to future growth of the petrochemical industry.

National Growth

1. The petrochemical industry is reaching maturity and future growth rates will approach the Gross National Product Rate.^{17/} (For projection purposes the rate of 3.75 percent, compounded annually, as projected in the Senate Select Committee Print No. 5^{22/} was used. Current trends indicate that the industry growth rate, which is currently about 10 percent^{17/} and dropping, will level out near the GNP rate about 1975.)

2. Ratios between the petrochemical groups aliphatics, aromatics, and inorganics will be approximately the same as the ratios projected by the Oil and Gas Journal^{17/} through the year 1965.
3. Ethylene is expected to remain one of the leading aliphatic petrochemicals and the assumption is made that the future production ratio of ethylene to total aliphatics will be approximately the same as the ratio projected by the Oil and Gas Journal^{17/} for 1965. (Although there is a feeling among some in the chemical industry that other aliphatics may some day replace part of the ethylene market, there is no basis for forecasting a change in the near future and the percent of reduction in the ethylene market cannot be foreseen.)
4. The future production ratios of ammonia, carbon black, and sulfur to the total inorganic production are expected to approximate present ratios.
5. The main intermediate petrochemicals - polyethylene, ethyl alcohol, ethylene oxide, and ethylene dichloride - produced from ethylene are expected to have future production ratios to total ethylene production comparable to present ratios. (This assumption is made with the following limitation: Should the automotive industry go to more permanent antifreezes, the demand for ethylene glycol would drop off unless other uses can be found for the product. If this happens, the demand for ethylene oxide - from which ethylene glycol is derived - may drop off.)^{15/}

Prorating National Growth to the Arkansas and Red River Basins

The assumption is made that major opportunity for petrochemical expansion in the Ark-Red basins is in the utilization of ethane and natural gas as feedstock and in the production of the inorganic petrochemical, ammonia, and the aliphatic petrochemicals forecasted for the area by the Department of Commerce report, Location Factors in the Petrochemical Industry^{21/}. The major types of petrochemicals which appear to be more favorable than other chemicals for production in the study are:

EXHIBIT C-12

Ethylene Glycol
Acrylonitrile
Hydrogen Cyanide
Ethanolamines
Ethylene Oxide
Ammonia
Acetic Anhydride
Acetic Acid
Acetaldehyde
Ethyl Alcohol
Formaldehyde

Methanol
Polyvinyl Acetate
Polyvinyl Chloride
Vinyl Acetate
Vinyl Chloride
Urea
Polyethylene
Ethylene Dichloride
Methyl Chloride
Ethylene
Acetylene

In determining the types of chemicals as well as the percent of national petrochemicals that might originate in the Ark-Red basins, the methodology utilized in the comprehensive study^{21/} by the Department of Commerce was adopted. The procedures adhered to by the study included the following considerations.

1. Regional availability of raw materials.
2. Regional cost differentials in petrochemical production.
3. Regional transport cost differentials.
4. Economies of scale (plant capacity).

As indicated in the study, petrochemical production in the basins is expected to be limited to low tonnage chemicals (except in a few areas which will have access to water transportation).^{9/}

Areas and Expected Growth

The petrochemical manufacturing centers in the study area are expected to remain essentially the same with the possible addition of a few areas such as Garden City, Kansas, which has access to needed feedstock from large nearby gas fields and agricultural markets for fertilizers in Kansas.

The areas of expected petrochemical expansion and the percent of total basin expansion expected to originate in these areas are given in Table C-5.

Table C-5

General Areas of Expansion and 2020 Production

<u>Area</u>	<u>% of Basin Expansion</u>	<u>Yearly Prod. (Million lbs.)</u>
Monroe, La.	14	5,428
Shreveport, La.	13	5,040
Amarillo, Pampa, Borger, Tex.	13	5,040
Longview & Marshall, Tex.	13	5,040
Ponca City & Tulsa, Okla.	12.5	4,846
Wichita, Kansas	12.0	4,652
El Dorado, Ark.	11.0	4,265
Garden City, Kansas	8.0	3,102
Wichita Falls, Texas	3.5	1,357

It should be pointed out that there are many influencing factors which are difficult to predict in projecting future growth of the petrochemical industry. Company initiative in deriving new production techniques, new chemical processes, and finding new uses for petrochemical feedstock cannot be predicted. Political controls on feedstock (oil and gas production) are also difficult to forecast. Any number of unpredictable factors could effect the accuracy of such projections.

Petrochemical Water Demands

The following methodology is utilized in projecting petrochemical water demands.

1. Demands prorated among areas in the Ark-Red basins in tons of production were tied to unit water demand^{21/} to obtain a total cooling water demand based on once through use.
2. The expected areas of petrochemical manufacturing expansion were then investigated more thoroughly as to availability of water to determine the percent of the once through cooling water requirement which could be supplied by the area if recirculation were practiced. The percentage thus established is used to determine the total cooling water demand for each area.

3. The total projected water demand was determined by adding the cooling water demand with a constant demand for miscellaneous needs.

The following assumption is used:

The future once through cooling water requirement per unit of production will approximate the present requirements listed in the Department of Commerce Report, Location Factors in the Petrochemical Industry.^{21/} As determined from this report, the average cooling water demand for the types of petrochemicals expected to be produced in the basins is 42 gallons per pound (84,000 GAL./ton.)

Projected petrochemical water requirements for the study area are given in Table C-6.

Table C-6
Projected Petrochemical Water Demands in the Study Area

State	Sub-area	General Area of Expansion	Cooling Water		Projected Demand (mgd)	Water for Other Purposes (mgd)		Total Water Demand (mgd)
			Once thru Demand Per Ton of Prod. (Gal.)	Recirculation (% of once thru)				
Texas	T-2	Amarillo	84,000	5	32	18		25
	T-3	Pampa & Borger	84,000	5	32	18		25
	T-8	Wichita Falls	84,000	5	9	5		14
	T-18	Longview & Marshall	84,000	15	92	19		111
Okla.	O-5	Ponca City	84,000	15	40	8		48
	O-6	Tulsa	84,000	15	40	8		48
Kan.	K-1	Garden City	84,000	5	19	12		31
	K-8	Wichita	84,000	5	29	17		46
Ark.	A-11	El Dorado	84,000	20	82	12		94
La.	L-1	Shreveport	84,000	20	125	18		143
	L-3	Monroe	84,000	20	130	20		150

*Includes process, sanitary, and miscellaneous uses.

Natural Gas Processing

Background and Future Outlook

The natural gas processing industry exerts a significant water demand in the production of natural gasoline* and light hydrocarbon streams* from natural gas.

As shown in Table C-7, a large portion of the United States gas reserves and gas processing industry is within the Ark-Red basins. While the gas industry in the basins appears to be firmly implanted, several factors should be pointed out in regard to long range projections of future growth in the region.

The national rate of consumption is increasing faster than the increase in reserves. In 1957, the demand was 11.3 trillion cubic feet and the reserve increase was 20.1 trillion cubic feet.^{6/} In 1960, the demand was 13 trillion cubic feet and the increase in reserves was 10.8 trillion cubic feet.^{6/} The national reserve total January 1, 1961, was 273.37 trillion cubic feet (a 21 year supply with present consumption rates).^{6/}

Since the trend of gas discoveries is downward and the trend of gas consumption is upward, there is presently some concern over the future of this industry. If this trend continues, expansion may be curtailed in very few years. Since pipelines and distribution systems are financed on 20 year bonds, reserves must always assure at least a 20 year supply.^{23/} If supply fails before the facilities are amortized, the bonds will not pay out.

The peak in United States gas reserves is expected around 1980.^{6 23/} Conservative estimates indicate the total United States reserve will reach around 425 trillion cubic feet with annual consumption increasing to about 20 trillion cubic feet by this time.

Several factors improve an otherwise uncertain outlook in the study area for the gas processing industry and petrochemical plants utilizing natural gas as feedstock. They are:

1. As pointed out in the discussion on petroleum refining, new methods of secondary recovery may make possible a much greater recovery of the gas potential of a field.^{9/}

*The natural gasoline and light hydrocarbons (liquefied gases and ethane) separated from natural gas in natural gasoline plants are commonly referred to as NATURAL GAS-LIQUIDS.^{24/}

Table C-7

Major Gas Reserves in Ark-Red Study Area ^{a/ 25 26/}

State	Study Area	Gas Refineries ^{27/}		Gross	1961 Total Reserves (million cf)		
		Number	Capacity 1961 (Million cf/d)	Withdrawals 1958 ^{28/} (Million cf)	Study Area	State	
	-----Counties-----						
Arkansas	Franklin	7	439	48,000	1,440,000	1,440,000	
	Columbia						
	Lafayette						
	Pope						
	Sebastian						
	Union						
	Plus 7 Counties of Less Significance						
	TOTAL	7	439				
Oklahoma	Entire State	53	2,200				
	(Major Counties)						
	(Texas ^{b/})						
	(Beaver)						
	(Garvin)						
	(Oklahoma)						
	(Beckham)						
		TOTAL	53	2,200	719,794	17,400,000	17,400,000
Kansas	Hugoton Area:	8	1,605		15,000,000 ^{c/}		
	Finney						
	Grant						
	Hamilton						
	Haskell						
	Kearny						
	Morton						
	Seward						
	Stanton						
	Stevens						
		South Central	4	235		5,000,000	
		TOTAL	12	1,840	562,000	20,000,000	20,500,000
	-----Fields-----						
Louisiana	North La. Area (Except Major Fields)	21	1,209		3,536,000		
	Major Fields:						
	North La.				1,400,000		
	Ark., La., & Texas ^{d/}				1,300,000		
	E. Texas & N. La. ^{e/}				1,100,000		
	Monroe				300,000		
		TOTAL	23	1,584	210,000 (Prorated)	6,236,000 ^{f/}	67,500,000
Texas	East Texas Area (Except Major Fields)	25	1,900		3,135,000		
	Major Fields:						
	East Texas				3,350,000		
	Ark., La., & Texas ^{d/}				1,300,000		
	E. Texas & N. La. ^{e/}				1,100,000		
		Hansford County	36	4,100		389,000	
		Panhandle - Hugoton ^{e/}	20	619		37,000,000	
		North Texas				400,000	
		TOTAL	81	6,619	1,340,000 (Prorated)	28,174,000 ^{f/}	122,500,000
	Study Area	TOTAL	176	12,702		73,250,000	
Eight States ^{h/}	TOTAL	495	34,957			248,875,000	
United States	TOTAL	633	40,520			262,600,000	

^{a/} Only the individual reserves with cumulative production of at least 100 billion on January 1, 1960, are listed separately here. In other words, the total reserves shown in the Ark-Red area for Texas and Louisiana would increase considerably if all known reserves were included.

^{b/} Texas, Beaver, and Beckham Counties are in part of the above field. Total gas reserves in major fields in the Ark-Red basins - approximately 73 trillion cubic feet.

^{c/} The Panhandle - Hugoton area includes counties in Texas, Oklahoma, and Kansas. Since the actual amount of this large reserve included in each State is not known, for estimating purposes the reserve is assumed divided approximately as follows: Texas, 50 percent; Kansas, 40 percent; and Oklahoma, 10 percent. Of the 37 trillion cubic feet total, Texas would then have about 18.5 trillion cubic feet in the reserve, Kansas about 14.8 trillion cubic feet, and Oklahoma about 3.7 trillion cubic feet.

^{d/} Since the exact breakdown is not known, the reserves in this field are assumed equally divided among the areas listed.

^{e/} Same as above.

^{f/} This figure is less than the column total (Notes d and e).

^{g/} This figure is less than the column total (Note c).

^{h/} These totals are for the entire States of Colorado, New Mexico, Kansas, Oklahoma, Texas, Missouri, Arkansas, and Louisiana.

2. Future progress in obtaining a high quality gas from coal may make available for local fuel and feedstock use much of the gas reserve in the Ark-Red basins which is committed to the large fuel industry in the East.^{21/}
3. The large network of gas lines from most of the major fields in the eight states partially included in the basins pass through the Ark-Red region on their way to markets in the East. As reserves are depleted, industries in the AWR area could obtain gas from these sources. In 1960, the eight states partially included in the basins held 95 percent of all the United States gas reserves.^{25/}
4. Another factor which is of major significance to the petrochemical industry is the small demand the petrochemical industry has on natural gas production. (In 1960, the demand on crude oil and natural gas was only 2 percent of the combined production of these industries.^{20/}

Future Industry in the Ark-Red Basins

In projecting future growth of the gas processing industry in the Ark-Red basins, it is assumed that the rate of expansion through the year 1980 will approximate the growth projected in Senate Select Committee Print No. 8.^{1/} The expected increase for the period is 53 percent over the 1954 level. As indicated in Print No. 8, production after 1980 is expected to level out and remain at about the same level. The present major gas processing areas in the basins are expected to remain the leading areas in the future with any capacity expansion centered around these locations. The vast natural gas gathering system now in the basins would be useful in transporting gas from new fields to processing centers.

Projected Water Demand

A total water demand for the gas processing industry in the Ark-Red basins was determined for the year 2020 to comply with the level of production given in Senate Select Committee Print No. 8. This water demand was then prorated among the expected processing centers as shown in Table C-8.

Table C-8

Projected Water Demands for the Gas Processing
Industry in the Study Area

State	Sub-area	General Area of Expansion *	Present Capacity (Million cf/d)	Processed in 1960 (Million cf/d)	Projected Maximum Water Demand** (mgd)	% of Maximum Water Demand Required With More Extensive Reuse		Projected Water Demand*** (mgd)		
						Cooling Water	Misc. Water	Cooling Demand	Misc. Demand	Total Demand
Texas	T-1	Sunray	2,170	793	73	5	3	4	2	6
	T-2	Dumas								
	T-3	Amarillo	200	66	8	5	3	1		1
	T-4b	Pampa-Borger	1,404	478	47	5	3	3	1	4
	T-7	Knox City	24	24	1	5	3			
	T-8		18	16	1	5	3			
	T-9		16	7	1	5	3			
	T-10	Graham	23	22	1	15	3			
	T-11	Springtown	459	287	15	15	3	2	1	3
	T-14		41	29	2	15	3	1		1
	T-15	Van	54	--	1	15	3			
	T-17		46	17	1	15	3			
	T-18		30	25	1	15	3			
	T-19	Longview-Marshall	509	308	11	15	3	2		2
		Carthage	1,292	892	25	15	3	3	1	4
Ark.	A-9	Stamps	58	53	1	20	3			
	A-10	Magnolia	350	252	7	20	3	2		2
	A-11	El Dorado	31	16	1	20	3			
Kan.	K-1	Ulysses	1,605	1,234	54	5	3	3	1	4
	K-4	Medicine Lodge	60	--	2	5	3			
	K-8	Wichita	120	118	4	5	3	1		1
	K-9	Attica	55	44	2	15	3	1		1
La.	L-1	Cotton Valley	549	264	12	20	3	2	1	3
	L-2	Huston	248	152	5	20	3	1		1
	L-3	Monroe	325	325	6	20	3	1		1
	L-4	Waterproof	154	136	3	20	3	1		1
Okla.	O-1	Booker	692	387	23	5	3	2		2
	O-2b	Elk City	285	266	10	5	3	1		1
	O-3		28	28	1	5	3			
	O-4	Covington	50	21	2	5	3			
	O-5	Blackwell	302	260	10	15	3	2		2
	O-6		62	36	2	15	3			
	O-7	Chandler	109	65	4	10	3			
	O-8	Oklahoma City	245	82	8	5	3	1		1
	O-9	Lindsay	807	551	27	5	3	2		2
	O-13	Healdton	103	88	3	15	3	1		1
	O-14		86	61	3	15	3			
	O-20		15	15	1	15	3			
TOTAL			12,625	7,416						

*Subareas with no particular areas of expansion listed have no significant demand centers.

**Includes little or no reuse.

***Includes extensive reuse.

Pulp and Paper

The study area now produces 5 percent of the total United States pulpwood consumption. By extrapolating the projection made by the Forest Service ^{28/} from 2010 to 2020, the United States consumption of pulpwood in 2020 will be 160 million cords. Assuming that the study area will still produce 5 percent of the Nation's demand, the 2020 study area output will be 8 million cords.

The following data were tabulated by subarea.

Area	<u>29</u>	<u>30</u>	<u>31</u>	<u>32/</u>
Area of commercial forests	<u>29</u>	<u>30</u>	<u>31</u>	<u>32/</u>
Volume of growing stock, soft and hardwood	<u>29</u>	<u>30</u>	<u>31</u>	<u>32/</u>
Pulpwood production for 1946	<u>33</u>	<u>34</u>	<u>35</u>	<u>36/</u>

The area of softwood forests was estimated by multiplying the area of commercial forests by a ratio $\frac{\text{volume of softwood growing stock}}{\text{volume of total growing stock}}$, developed from tabulated data for each subarea. The Forest Service indicates that some forests can produce 1.25 cords of softwood per acre of forest with controlled forestry practices. ^{28/} By assuming an average 2020 production of 0.60 cords per acre of softwood forest, there will be sufficient pulpwood to meet projected demands.

This (0.6 cord/acre) rate of production was applied to the area of softwood forest and the projected production of pulpwood summarized by subareas.

Proposed paper mills were located considering pulpwood availability, barge transportation (existing and proposed), and sufficient supply of appropriate quality water.

Mill capacities and their water demands were calculated by using the following conversion factors: 1.75 cords of pulpwood per ton of wood pulp ^{28/} and 35,000 gallons of water per ton of wood pulp. ^{37/}

Projected water demands for the pulp and paper industry are given in Table C-9.

Table C-9

Projected Pulp and Paper Production and Water Demands

Subarea	Area 1,000 Acres	Commercial Forests Area - 1,000 Acres		Pulpwood Production Cords Per Day		Paper Mill Capacity No. of Plants/ Tons Per Day		2020 Water Demand (mgd)
		Total	Estimated Softwood	Actual 1959	Projected 2020	Actual 1958	Projected 2020	
T-12		244	164	10	270	1/40	1/40	1.4
T-15	1,010	649	113	64	186			
T-16	1,405	661	164	120	270			
T-17	1,207	465	216	164	356		1/800	28.0
T-18	815	631	306	147	504			
T-19	1,167	149	5	24	8			
O-16	433	983	74	-0.1	121	1/90	1/90	3.1
O-17	1,621	1,610	1,190	20	1,950			
O-19a	2,323	1,920	1,070	60	1,760	1/700	1/700	24.5
O-19b	2,559	1,707	178	-0.4	283	2/1,400	2/1,400	49.0
A-2	2,268	3,595	1,920	202	3,150		1/2,000	70.0
A-3	4,815	138	45	0	74			
A-4	339	2,055	1,420	451	2,330			
A-5	2,472	371	257	43	421			
A-6	437	565	232	82	381			
A-7	1,060	1,169	68	5	112	2/880	3/544	32.9
A-8	2,668	1,951	1,200	423	1,970			
A-9	2,696	650	354	246	562			
A-10	886	955	503	452	828			
A-11	1,146	1,745	1,020	860	1,680	1/600	2/1,220	42.5
A-12	2,036	1,516	670	460	1,100			
A-13	2,405	905	312	354	512	1/655	1/655	22.9
L-1	1,509	3,717	2,060	1,960	3,430	2/1,480	2/1,480	51.8
L-2	4,905	627	168	185	277	1/580	1/580	20.3
L-3	926	2,149	76	166	125	2/1,725	2/1,725	60.3
L-4	3,361	623	316	202	518			
L-5	830	645	226	144	373		1/500	17.5
L-6	851							

Primary Metals

Iron and SteelBackground

The iron and steel industry in the Arkansas and Red River basins is presently centered at two locations.^{38/}

1. Colorado Fuel and Iron Plant at Pueblo, Colorado.
2. Lone Star Steel Plant at Lone Star, Texas.

CF&I Plant

The largest of CF&I's nationwide network of 11 steel plants, the Pueblo plant (which has been in operation for almost 88 years) has a steel ingot capacity of 1.8 million net tons which will soon be increased by 0.6 million net tons.^{39/} A completely diversified plant, the Colorado plant manufactures over 1,300 products for distribution throughout the world. The plant has had an average steel production since 1950 of 1.3 million net tons.^{40 41/} Iron ore used by the plant comes from the following sources:^{41/} Company mines in Wyoming, Utah, and New Mexico and foreign imports. Coal used by the plant comes from the following sources: CF&I mines in Colorado and New Mexico, privately owned mines in Colorado and New Mexico, and mines in Arkansas and West Virginia.

Lone Star Plant

The rebuilding of the present steel industry in east Texas in the early 1940's resulted from the increased demands for steel for production, refining, and transmission equipment in the petroleum industry.^{42/}

The largest and most important iron ore deposits in the Arkansas-White River basins are in northeast Texas. These deposits are the only resources of the basins having sufficient size and grade to support an integrated iron and steel mill.^{19/}

The existing industry has become firmly established on the basis of regional demand for its products, adequate iron ore reserves, and availability of large supplies of other necessary raw materials such as coking coal and limestone and dolomite within economic shipping distances from the furnaces.

The Lone Star plant became the Nation's first plant to use natural gas for blast furnace fuel. This source of fuel is obtained from the nearby east Texas gas fields.^{43/}

The east Texas iron ore reserve (usable quality) is estimated at about 160 million tons.^{42/} At present production rates this supply would be exhausted in from 30 - 40 years. Due to the grade of ore mined, about twice as much ore is mined as is produced in order to obtain an equivalent quantity of iron. The future of the east Texas plant may largely depend on the development of huge quantities of low grade ore in the area.^{19/} Development of the full potential of the east Texas reserve has been checked until satisfactory ore dressing methods can be found which would enable upgrading of the low grade ores.^{19/}

Present steel capacity of the Lone Star plant is 0.8 million tons per year. Production in May 1961 was near capacity.^{44 45/}

Future Growth

The following assumptions are made in regard to future iron and steel industry in the study area.

1. Most of the industry expansion in the foreseeable future will take place at the two existing locations.

Cognizance should be given to the bituminous coal reserves in southeastern Oklahoma as a possible future location for limited iron and steel production. Located in Sequoyah, Haskell, and LeFlore counties, the fields are within easy reach of the authorized Arkansas navigation project. An industry locating in this area would have access to needed coking coal and economical water transportation.^{46/}

As evidenced by present iron ore production, the increasing ratio of crude to usable ore and the extent of U.S. reserves,^{47/} within the next sixty years the U.S. iron and steel industry will have to go to foreign imports for most of its crude ore. As this trend develops, industry is expected to tend toward market orientation, locating near the coast and/or inland waterways.

The east Texas steel industry, currently using coal from southeastern Oklahoma, and the Colorado industry are undergoing considerable expansion and becoming fully diversified. As these industries, which are located at opposite ends of the basins grow, they are expected to meet most of the basin demands. Increased demands for steel in central and northern Oklahoma may, however, result in the location of a small plant on the Arkansas near these growing market areas.

2. The future annual rate of growth or expansion for the industry presently in the basins will approximate the projected national iron and steel annual expansion rate which are:

- (1) Steel ingot production -- 2 %
- (2) Pig iron production -- 1 %

The influence of aluminum, plastics, fiber glass, and other materials on steel demand is expected to be greater in future years than it has been in the past. While such an influence is unpredictable, some consideration should be given in projecting future demands for steel products. The historical rate of increase in steel production since 1915 has been about 2½ percent, compounded yearly.^{47/} Notwithstanding encroachments of other materials in heavy steel using industries such as, the automotive and building construction industries, the future growth of the steel industry is expected to continue in a similar fashion to the historical trend. As a basis for projecting future demands, it is assumed that steel production will increase at about 2 percent per year, a slight change from past trends due to expected influence from the other material industries.

3. The water requirements per pound of steel produced will remain about the same.
4. Advanced technology in the dressing of iron ores will make possible the use of large quantities of low grade ores.

Future production and water demands for the iron and steel industry in the study area are given in Tables C-10 and C-11, respectively.

Table C-10

Production

<u>Location</u>	<u>Present Production</u> <u>(Yearly)^{40 41 45/}</u>	<u>2020 Production</u> <u>(Yearly)</u>
Pueblo, Colorado	1.3 million tons	4.26 million tons
Lone Star, Texas	0.8 million tons	2.62 million tons

Table C-11

Water Demands

<u>Location</u>	<u>Present</u>	<u>2020</u>
Pueblo, Colorado	75.6 mgd	248 mgd*
Lone Star, Texas	10.2 mgd	33.4 mgd

*This is a once through demand. The plant manager at Pueblo states that by recirculating cooling waters and making use of ammonia steel liquors for quenching, they could triple capacity. The present company supply could then be utilized to meet the projected water demand.^{39/}

Aluminum

A study of the aluminum industry in Arkansas indicates that the present level of production may be sustained through the year 2020.

Present aluminum production in the Ark-Red basins is confined to Clark and Hot Spring Counties in Arkansas. Alumina reduction plants are located near Arkadelphia and Jones Mills and have a capacity of 164,000 short tons per year (6.8 percent of the U.S. capacity).^{47/}

The most important deposits of bauxite, the principal ore used in the production of alumina, occur near Little Rock and Bauxite, Arkansas.^{47/} Centers of the two bauxite areas, which cover about 15 square miles, are approximately 14 miles apart.

In 1959, 96 percent of the U.S. production was produced from these deposits.^{47/} The Arkansas deposit is not homogeneous and would, therefore, vary in its value as alumina feedstock.^{9/} This should be considered in evaluating the bauxite reserve.

Present bauxite reserves in Pulaski and Saline Counties are estimated to be approximately 50 million tons (mined and dried equivalent).^{*} If the rate of production experienced from 1950 - 1960^{47/} by this area continues, the estimated reserve will be depleted in about 31 years. However, aluminum industries now operating in the area could import bauxite or alumina from mines in Jamaica, Haiti, and other overseas locations of bauxite reserves.^{47/}

^{*}The Bureau of Mines^{19/} estimated that as of January 1, 1946, the bauxite reserve contained:

Approximately 40 million long tons of 32 percent aluminum bauxite (mined and dried equivalent)

Approximately 25 million tons of submarginal bauxite

Approximately 3.5 million tons of high iron bauxite

Approximately 63,300,000 tons of bauxitic clay

Bauxite production in the basins since 1946 has totaled about 20.3 million tons.^{6 47/} During this period about 5.5 million tons of new reserves have been developed. As a basis for projecting useful life of the reserve, it is assumed that as of January 1, 1960, the reserve of bauxite on a mined and dried basis that can be used economically under existing conditions was approximately 50 million tons.

EXHIBIT C-27

After completion of the Arkansas River navigation canal,^{11/} water shipment will be available to within 40 miles of present aluminum reduction plants. While the availability of water shipment may help maintain the present level of production, little expansion above this level is expected in the area due to the large electric power demands needed in the reduction of alumina.

The largest cost item involved in the smelting of aluminum is electric power.

Approximately 15 kilowatt-hours of electric power is required to produce a pound of aluminum.^{48/}

At an average of approximately 2 mills per kilowatt-hour, the percentage of net plant costs per pound of aluminum for power is from 16 - 21 percent.^{48/}

Since electric power costs, bauxite extraction costs, and transportation of alumina to smelter constitute most of the cost in producing aluminum, expansion of the industry is expected to occur in areas where large quantities of cheap hydroelectric power is available, such as Canada and Alaska or in coastal areas such as the Gulf which are nearer to the source of alumina and natural gas or some other form of fuel which can be used to produce thermoelectric power. In the latter case, the high cost for electric power is offset some by lower transportation costs.

Assuming the present level of production will continue, water demands for the aluminum industry in Arkansas in the year 2020 will be approximately 12 mgd near Arkadelphia in Subarea A-5. Water requirements in the production of alumina from bauxite are small. The industry average is approximately 0.66 GAL. per pound of alumina.^{48/} Water requirements for reduction plants, however, are much higher. The industry average is 14.62 GAL./lb. of aluminum.^{48/} To determine the projected water demand, a yearly production of 90 percent^{47/} of capacity was assumed and the average unit water demand used.

*The U.S. aluminum industry averaged 86 percent in 1959.

Food and Kindred

The food and kindred industry is one of the principal water using industries of the United States. Its water requirements accounted for 5.6 percent of the total industrial water demand during 1954. Of this total, 50 percent was used for cooling and air conditioning and 25.5 percent for processing.^{49/}

The food and kindred industry, covered under Standard Industrial Classification (SIC) 20, includes plants engaged in manufacturing of meat products, dairy products, bakery products, sugars, beverages, canned, frozen, and preserved fruits and vegetables, confectionary and related products, miscellaneous food preparation, and feed.

Based on historical and current changes within the food and kindred industry, certain assumptions were developed to govern projection of future water demands. These criteria assume that:

1. Man-hour requirements per unit of production will be gradually reduced.
2. Upward trends in automation will increase water requirements per employee.
3. Most industries will experience little, if any, change in the water requirements per unit of production.
4. A few industries, because of automation, will experience a reduction in water demand per unit of product.
5. Other industries in which automation will increase water requirements will stabilize demand per unit of product by increased recirculation.
6. Water demand per unit of production is a more reliable basis for projection.
7. Rates of production projection, presented in Senate Select Committee Print No. 12, Table 2, "Domestic Requirements for Farm Products, 1954 and 1958, and projected for 1980 and 2000," would continue to the year 2020.^{50/}

Data presented in the 1958 Census of Manufactures provide the base for projection. This publication lists food and kindred plants by four digit SIC number, by location, and by size of employment. The nine food and kindred subclasses are categorized by their water use significance in Tables C-12 and 13.

Table C-12

Significant Water Use

<u>SIC Subclasses</u>	<u>Industries</u>
2011-13-15	Meat and Poultry
2021-26	Milk, Cheese, Butter, Ice Cream, etc.
2031-37	Fruit, Vegetable, and Fish Processing
2061-63	Cane and Beet Sugar
2082-87	Alcoholic and Soft Beverage, etc.

Table C-13

Insignificant Water Use

<u>SIC Subclasses</u>	<u>Industries</u>
2041-46	Grain Milling and Preparation
2051-52	Bakeries
2071-73	Confectionary Products and Chewing Gum
2091-99	Oil Milling and Preparation

To determine the present water demands of the five selected subclasses, water departments and individual industries in the study area were contacted. Water demand for one or more years of record, types and quantities of products, and the number of employees were obtained. From these data the following water demand per unit of product and per employee were derived.

Table C-14

Unit Water Demand

<u>SIC</u>	<u>Gallons/employee/day</u>	<u>No. of Plants</u>
201	356	9
202	245	8
203	336	6
206	2,400	1
208	1,820	4
<u>SIC</u>	<u>Gallons/unit of production</u>	<u>No. of Plants</u>
202	3 /gallons of milk	4
203	1.5/lbs.	2
206	3,500 /ton	1
208	15 /case	4
2011-13	625 /head of cattle	2
2015	12 /bird	4

A separate investigation was made of the poultry processing industry, SIC 2015, to provide data for projecting this industry in northwestern Arkansas. Although this industry now averages 12.0 gallons per bird, it is assumed that its water demands would be 7.0 gallons per bird by the year 2020 because of recently developed equipment.

Most food and kindred plants are small and serve only the local area. These plants usually obtain their nominal supply of water from the municipal system and are included in the municipal per capita water demand. In analyzing data gathered on municipal water systems, industrial water intake totaling less than 10 percent of the municipal pumpage or fewer than 0.1 mgd are assumed to be better reflected in the municipal demand. Subareas in which food and kindred industrial water demand in excess of that included in the municipal demand are selected by the two methods.

Using data obtained from the 1950 Characteristics of the Population, a ratio was computed between food and kindred employees and total labor force for each subarea. For the entire study area food and kindred industrial employment averaged 2 percent of the total labor force in 1950. Subareas selected for additional study in which this percentage was equaled or exceeded and are listed in Table C-15.

Table C-15

Potential Food and Kindred Production Centers

<u>Reference City</u>		<u>%</u>	<u>Reference City</u>		<u>%</u>
Arkansas			Missouri		
A-1	Fayetteville	5.2	M-1	Joplin	3.6
A-4	Fort Smith	3.7	M-2	Aurora	2.5
A-7	Little Rock	2.1			
A-8	Stuttgart	2.3			
Colorado			Oklahoma		
C-4	Trinidad	2.7	O-4	Enid	3.6
			O-5	Ponca City	2.1
Louisiana			O-8	Oklahoma City	3.2
L-6	Alexandria	2.3	O-15	Muskogee	2.7
Kansas			Texas		
K-7	Newton	2.7	T-6	Plainview	2.2
K-8	Vichita	3.7	T-11	Sherman	4.3
K-12	Coffeyville	2.6	T-12	Dallas-Ft. Worth	3.3
K-13	Pittsburg	2.3	T-14	Greenville	2.1

Employment figures listed in the 1958 Census of Manufactures revealed additional subareas in which there are located several large plants with potentially large private water intakes. These subareas, also selected for study, are included in Table C-16.

Table C-16

Additional Areas Investigated

	<u>Reference City</u>	<u>Major Food and Kindred Production</u>
Texas		
T-1	Dalhart	Dairy Products and Canned and Frozen Vegetables
Colorado		
C-1	Pueblo and Colorado Springs	Meat and Dairy Products
Arkansas		
A-3	Van Buren	Poultry and Canned and Frozen Vegetables
Louisiana		
L-1	Shreveport	Dairy Products and Alcoholic and Soft Beverages
	Thibodaux	Sugar
Oklahoma		
O-6	Tulsa	Dairy Products
Kansas		
K-11	Emporia	Meat

The 1958 base is converted from employment to units of production by the developed water demands. Production for each of the five selected food and kindred subclasses are projected by subareas to the year 2020, using rates developed for the Senate Select Committee. Water demand is calculated by multiplying each projected production by the appropriate gallonage per unit of product. These individual water demands for the five subclasses are summed for each listed subarea under study. In these subareas there is reason to believe a substantial portion of the food and kindred water demand is in excess of that included in the municipal projection. In addition, many of the food and kindred plants whose water demands are

usually a part of the municipal demand are not included in the five SIC subclasses selected as significant water users. Taking the types of major food and kindred plants in each subarea and the above facts into consideration, between 80 and 100 percent of the calculated water requirements is assumed to be the food and kindred industry water demands.

In addition, present plans for a Campbell Soup Company plant in subarea T-13 (Paris) will require 2.0 mgd initially with an ultimate demand of 8.0 mgd expected to develop by 1965. Smaller food processors anticipated to locate in the area should create an additional demand of approximately 10 mgd. Total water use by the food processing industry will reach 18 mgd by the year 1970.^{51/} Paris's average municipal water demand in 1959 was 2.40 mgd, a small portion of the projected food and kindred demand; therefore, projected municipal demand will not account for any of the projected food and kindred water demand.

Projected 2020 food and kindred water demands are given in Table C-17.

Table C-17

Projected Water Demands

<u>Subarea</u>	<u>Reference City</u>	<u>Projected 2020 Food and Kindred Water Demand (mgd)</u>
Texas		
T-1	Dart	0.5
T-6	Flview	0.1
T-11	Shan	0.3
T-12	Das - Fort Worth	10.0
T-13	Pe	18.0
T-14	Gaville	0.8
Colorado		
C-1	Plo and Colorado Springs	1.5
C-4	Tidad	4.0
Oklahoma		
O-4	En	0.4
O-5	Pa City	0.9
O-8	Ohoma City	1.9
O-15	Mogee	0.8
O-8	la	1.9
Arkansas		
A-1	Itteville	6.0
A-3	Wburen	4.5
A-4	W Smith	1.0
A-7	Lie Rock	2.5
A-8	Stgart	0.3
Louisiana		
L-1	Shveport	1.6
L-4	Tulah	2.3
L-9	Aandris	1.0
Kansas		
K-7	Won	0.2
K-8	Wita	2.2
K-11	Bria	1.7
K-12	Cayville	0.4
K-13	Wsburg	0.8
Missouri		
M-1	jin	1.2
M-2	ara	1.7

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Agricultural Water Demands

Since the principal agricultural water use in the study area is for crop irrigation, evaluation of possible agricultural benefits is confined to this use. Benefits will accrue when the demand for cropland is facilitated by irrigation that could not occur without the improvement in water quality afforded by the proposed natural brine control works. To complete this portion of the overall benefits evaluation, a series of assumptions, applicable to agricultural water demands only, is necessary.

Assumptions

1. Agricultural water use will be secondary in priority to municipal and industrial water uses.
2. Rural residential and livestock water use, being comparatively minor and widespread, will be satisfied from ground water sources or small impoundments, and only water required for crop irrigation will be considered.
3. Projected irrigation will develop first along streams having a sufficient quantity of good quality water (electrical conductivity less than 1,000 micromhos).
4. All projected irrigation utilizing surface waters will be achieved by use of presently constructed or firmly committed projects and streambank pumping facilities operated by individuals.
5. Since much of the return flow from bank plant irrigation re-enters surface streams via ground water aquifers in an undefinable manner, the effects of return flows from individual (non-project) irrigators are not assessed.

Methodology

Irrigation water demands are derived from an examination of irrigated lands, irrigable lands, irrigated acreage projected to the year 2020, water requirements for crops, water quality of surface streams, and future agricultural efficiencies.

EXHIBIT D-2

The basis for analyzing variations in agricultural production and irrigation water requirements are type-of-farming areas developed from classifications used by the Bureau of the Census. These farming areas, shown in Figure D-1, are based on: (1) type of crops; (2) type of livestock programs; (3) rainfall, and (4) length of growing season. Table D-1 tabulates the number of commercial farms by product or crop.

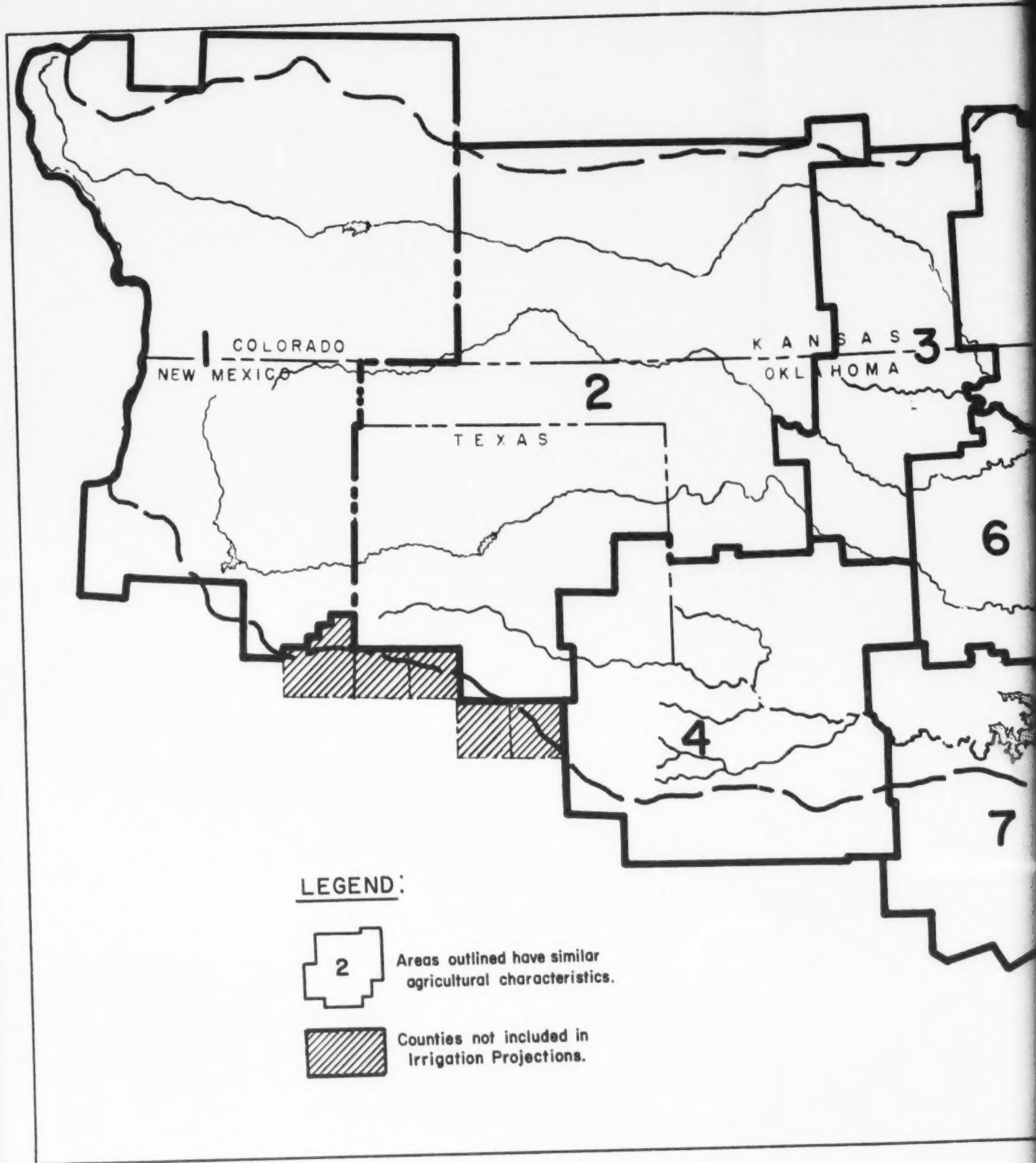
Irrigation projections are founded on information developed for the Senate Select Committee by the U.S. Department of Agriculture. ^{1/} The findings of this Committee base projected irrigation needs on a projected per capita requirement for food and fiber and the projected high, medium, and low 1980 and 2000 national populations. From these data, the U.S. Department of Agriculture ascertained agricultural acreage, both dry and irrigated, needed to satisfy the projected total demand for food and fiber, also taking into consideration future imports and exports. National acreages then were allocated to dryland and irrigated land needed in each major river basin.

Curry County, New Mexico and Parmer, Castro, Floyd, and Hale Counties, Texas, are deleted in the Ark-Red irrigation study to conform to the river basin subdivisions used in Senate Select Committee projections (see Figure D-1). Although portions of these counties are within the Red River basin, inclusion of the extensive irrigated acreages in these counties (almost 1½ million acres in 1959) would inflate the study area base for projection and result in distortion of the anticipated basin share of national irrigation expectations. The Ark-Red study area, thus adjusted, is approximately the same as the Upper and Lower AWR basins, and expected growth rates for this part of the U. S. total is deemed applicable to the study area.

The Senate Select Committee's year 2000 irrigation projection for the medium population, geometrically extrapolated to 2020, indicates irrigation acreage will increase approximately 100 percent in the Upper AWR area, and 350 percent in the Lower AWR area. Farming areas 1 through 7 are designated as the Upper study area; and the remaining, 8 through 11, make up the Lower study area.

Table D-1
 Type of Farms by Type-of-Farming Area 2/
 (Number of Farms)

Type-of-Farming Area	Cash Grain	Cotton	Other Field Crops	Vege- tables	Fruit & Nuts	Poultry	Dairy	Live- stock Farms	Live- stock Ranches	General	Misc.
1	2,359	21	206	92	21	185	469	5,166	3,084	876	3,168
2	15,651	834	94	17	--	166	667	8,668	1,721	1,420	3,808
3	14,976	131	--	30	--	157	1,265	4,656	353	1,724	4,647
4	2,986	8,874	546	5	--	164	662	5,326	2,243	2,866	5,950
5	5,538	26	--	50	--	242	2,235	9,347	807	375	11,521
6	933	700	425	61	--	193	1,425	7,040	2,252	1,340	13,996
7	1,245	6,196	483	66	--	520	2,010	8,254	3,100	1,870	16,903
8	1,627	70	45	68	440	3,060	5,406	5,733	232	951	17,270
9	644	1,115	248	146	412	1,445	1,285	5,187	1,203	603	18,964
10	169	3,547	671	271	88	1,325	1,429	6,043	1,901	664	21,609
11	2,126	14,091	219	50	27	327	572	2,771	491	627	14,402
Total	48,114	35,605	2,937	856	988	7,784	17,425	68,191	17,387	13,316	132,238



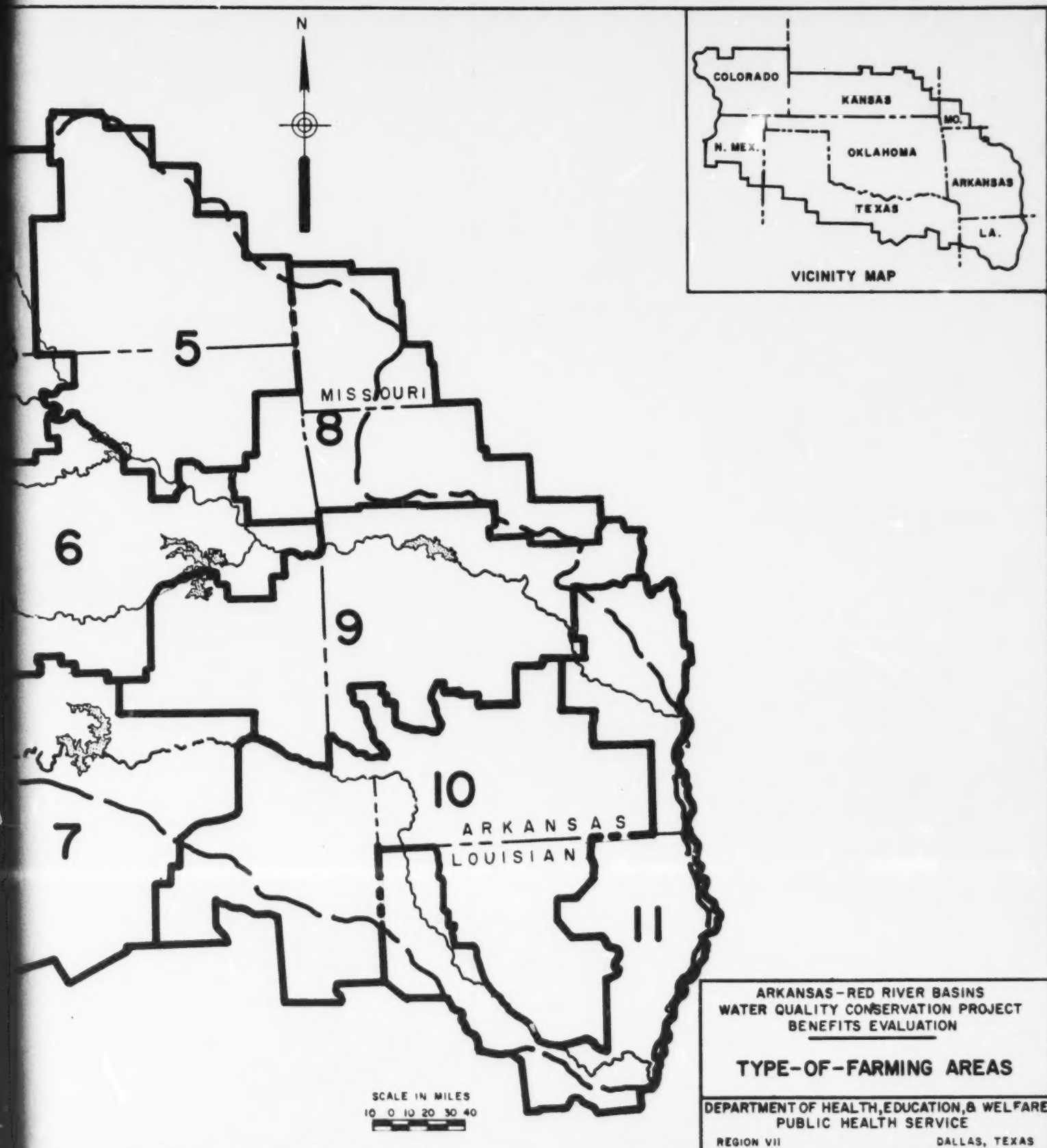


FIGURE D-1

EXHIBIT D-4

Irrigation projections for the study area appear in Table D-2.

Table D-1

Past and Projected Irrigation in the Study Area and the U. S. 2-3/
(1,000 Acres)

	1944	1949	1954	1959	1963
Upper Study Area	694	1,113	1,466	2,564	2,932
Lower Study Area	169	269	514	440	2,310
TOTAL	863	1,382	1,980	3,004	5,242
U. S.	20,539	25,905	29,552	33,211	71,000

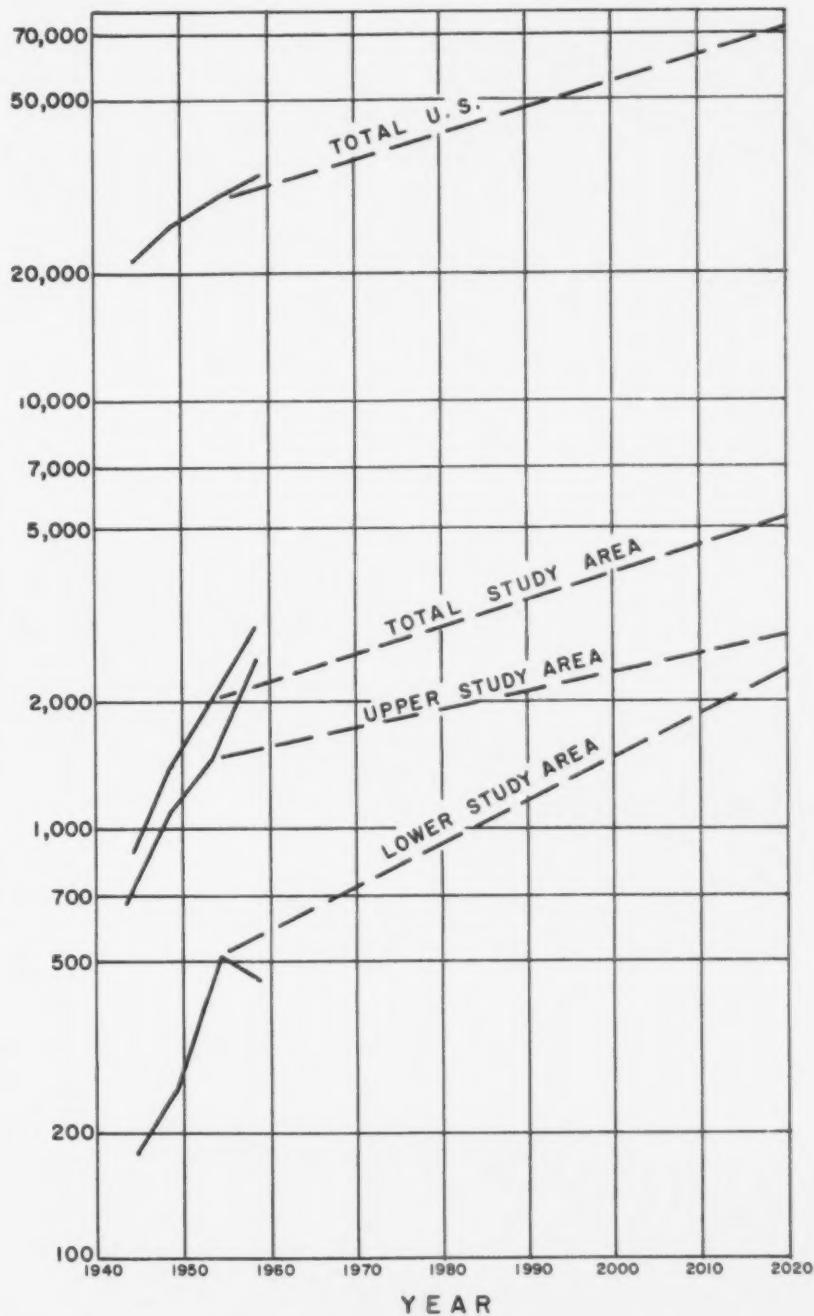
Irrigation projections presented in Table D-2 and depicted on Figure D-2 use 1954 irrigated acreages as a projection base. Data for 1959 are also included for comparison purposes. Examination of historic trends in Figure D-2 show that irrigated acreage projected growth rates of the Senate Select Committee were exceeded during the period 1954-59 for both the United States and the study area.

Rapid increases during this five year period in the Upper study area were due primarily to the extensive development of ground water irrigation in the High Plains region. This trend cannot be expected to continue indefinitely, since ground water is currently being wiped in part of this area, especially in the southern High Plains. 2/

The lower study area declined in acres irrigated from 1954 to 1959. This downward trend probably reflects the relatively high rainfall and its tortuous distribution in 1959, as compared with 1954. Over a period of time, supplemental irrigation is expected to increase substantially in the lower study area. This practice tends to stabilize the farm economy and allows the irrigator to take more efficient use of seed, fertilizers, equipment, and labor with more consistent and usually larger harvests. 3/

Study area irrigation acreage projection allocations to each farming area are the result of careful consideration of: past and present irrigation, lands suitable for irrigation, water quality suitable for irrigation, surface water quantity available for irrigation, and ground water reserves. Significant portions of these data are summarized in Table D-3.

ACRES IRRIGATED (IN THOUSANDS)



ARKANSAS-RED RIVER BASINS
WATER QUALITY CONSERVATION PROJECT-
BENEFITS EVALUATION

IRRIGATION
TRENDS AND PROJECTIONS

DEPARTMENT OF HEALTH, EDUCATION, & WELFARE
PUBLIC HEALTH SERVICE
REGION VII DALLAS, TEXAS

FIGURE D-2

Table D-1
Type-of-Farming Area Irrigation Data
(1,000 Acres)

Type-of-Farming Area	Acres Irrigated				Irrigable Lands
	1944	1949	1954	1959	
			Surface	Ground	Total
1	534	572	401	511	589
2	148	496	916	1,617	3,667
3	---	1	16	26	27
4	10	41	110	207	259
5	---	---	6	1	4
6	---	1	7	3	6
7	1	1	8	6	12
8	---	1	8	1	4
9	---	1	19	2	13
10	1	13	26	14	21
11	166	234	421	308	402
Totals	862	1,261	1,978	2,259	3,004
					13,113

* Totals may not agree with Table D-2 because of rounding.

EXHIBIT D-6

The irrigable lands data in Table D-3 for the Reclamation States include all lands suitable for irrigation, regardless of the quality or quantity of water available. These acreages are based on tabulations made by the Bureau of Reclamation for the Arkansas-White-Red River basins report of 1955. Irrigable lands data for Arkansas and Louisiana are based on tabulations made by the Soil Conservation Service.

Estimation of the total lands irrigated from surface supplies to be used are used to establish the aggregate amount of land that will be irrigated from surface sources, except in those areas where ground water is limited, or being depleted. For the latter, future groundwater irrigation considers estimated rates of recharge. Acreages only to the limit of industrial withdrawal water depletion are available in other parts of the same farming area to replace acreages forced out of production by exhaustion of local water supply.

Expectation is that, except for those projects presently constructed or firm commitments, all surface irrigation will be performed by individual watersheds irrigating through streambank pump plants. Firmly committed reservoirs containing irrigation storage are: Pecos, Canyon, and Rio Grande Reservoir in western Oklahoma, and Bayou Rapides and Bayou du Large Reservoirs in Louisiana. The Frying Pan-Ark Project located in Pueblo, Colorado, will not increase present acreages, but is intended to permit more efficient irrigation of existing acreages.

Estimation of acreages to be irrigated from surface sources by individual watersheds results from consideration of the quantity and quality of water available in each stream. First consideration is given to irrigable lands along streams which are assumed to have a sufficient quantity of good quality water available for irrigation.

Projected area irrigated acreage requirements for 2020 by expected water supply and type-of-farming areas, considering the above factors and limitations, is presented in Table D-4.

Table D-4

Projected 2020 Irrigation by Source

Type-of-Farming Area	Acres Projected		
	Surface	Ground (x 1,000)	Total
1	510	90	600
2	60	1,653	1,713
3	18	132	150
4	70	200	270
5	31	17	48
6	48	37	85
7	43	23	66
8	108	30	138
9	232	41	273
10	178	357	535
11	864	500	1,364

Projection of irrigation water needs to be met by surface sources makes necessary the determination of the month during the irrigation season when critical conditions of high crop water requirement and low streamflow would occur. Study of irrigation water requirements for the area revealed peak demands are generally exerted during the months of July and August. August is selected as the critical month, since streamflows usually average less than July. The assumption is that with sufficient water for irrigation during the month of August, adequate water would be available for irrigation during the rest of the season. Seasonal and August irrigation water requirements are shown in Tables D-5 and D-6, respectively.

Table D-5

Projected Annual Irrigation Water Requirements 17/

Type-of-Farming Area	Water Required By Plants (acre-inches/acre)	Efficiency of Application (percent)	Diversions Required (acre-inches/acre)
1	16	65	25
2	16	65	25
3	13	65	20
4	17	65	26
5	12	65	18
6	12	65	18
7	14	65	22
8	10	70	14
9	13	70	14
10	10	70	17
11	12	70	17

Table D-8

Projected August Irrigation Water Requirements ^{8/}

Type-of-Farming Area	Water Required By Plants (acre-inches/acre)	Efficiency of Application (percent)	Total Required (acre-inches/acre)
1	5	65	8
2	5	65	8
3	4	65	6
4	6	65	9
5	4	65	6
6	4	65	6
7	5	65	8
8	3	70	4
9	4	70	6
10	3	70	4
11	4	70	6

Efficiencies of application appearing in the above Tables are farm efficiencies and do not apply to project type irrigation. These are the most probable efficiencies presented for the year 2000 by the Senate Select Committee. ^{1/} Advancing technology in irrigation practices and improved management may make possible increased efficiencies in some areas; however, the efficiencies shown are assumed to represent average conditions expected in 2020.

Assuming that a reasonable allocation of waters to irrigation would result in no more than 50 percent depletion of projected mean August flows, sufficient supply will remain for other legitimate users. Projected quality assumptions provide for reduction in total dissolved solids to the level achieved by 85 percent reductions in sodium chloride emanating from other than the 15 natural salt source areas and 90 percent reduction in brines from the 15 project areas described in Chapter III.

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Stream Quality Determinations

In the final report this Exhibit will contain achievable chloride-duration data and computations. These data, in this draft, are based upon preliminary curves made available by the Tulsa District, U.S. Army Corps of Engineers.

Special Studies for Benefits Computations

Industrial Cooling Water Quality Requirements

Since at some locations, industry utilizes sea water for cooling purposes, ^{1/} it is deemed inadvisable to evaluate benefits for projected cooling water demands on the same basis used in evaluation of municipal and industrial process water demands. Benefits that might be ascribed to a reduction in the chloride level in cooling waters is investigated separately; therefore, to more clearly define the additional costs incurred by the presence of chlorides in recirculating cooling systems.

This investigation includes a review of available published data on cooling tower construction and operation with particular emphasis on cooling water recirculation and treatment. ^{2/} In addition, the question was discussed with representatives of power companies and power plant consultants. ^{3 4 5/} Letters were also circulated to manufacturing companies practicing recirculation of cooling water with high chloride levels and consulting laboratories specializing in industrial water problems. ^{6 7 8 9/}

Three possible areas of increased costs are explored-- initial construction and maintenance, operation, and water treatment. The following summarizes the findings:

1. The presence of dissolved chlorides in recirculating cooling systems (particularly in the range from 0 - 2,000 ppm) induces no appreciable increase in costs of the following items:

- a. Initial Construction and Maintenance--

Chlorides do not appreciably increase construction and maintenance costs. Increased chlorides are reported to have a deleterious effect on stainless steel (stress corrosion cracking); however, this is one of the most costly materials and is infrequently used. Chlorides do have a bearing on corrosion aspects but cannot be used as the only indicator. Where disposal problems militate against use of corrosion inhibitors such as chromates, other measures, i.e., lined pipe and differing metallurgical choices, might be required when concentrations exceed 500 ppm.

b. Operation--

Permissible number of cycles and frequency of blowdown are determined more by other factors such as calcium hardness, alkalinity, temperature, sulfates, and total solids (in other words, scale forming tendencies) rather than chlorides.

c. Water Treatment--

Since the chloride concentrations up to 2,000 ppm is not a determining factor, water treatment costs do not appear to vary significantly with its concentration.

2. The chloride concentration appears to be of significance only in its contribution to total solids, which is the usual governing factor in determining the permissible number of cycles and the frequency of blowdown.
3. The anticipated reductions of chloride ion concentration in waters which could be used for cooling purposes in the Arkansas and Red River basins would be of insignificant benefit to industry. Cooling water demands have therefore been excluded in computation of benefits.

Transmission Cost Computations

Transmission costs are developed for 2020 demand centers using standard curves developed for the Office of Saline Water Conversion. These costs for three subareas--O-3 (Oklahoma City), T-12 (Dallas-Fort Worth), and A-4 (Fort Smith) are separately computed using the following cost data:

A. Capital Costs

1. Pumping (pumps, motors, pump house and all appurtenances necessary for operation)--\$125. per installed horsepower.
2. Pipeline (in place cost-including valves, fittings, etc., and allowances for special construction of concrete pressure pipe).

EXHIBIT F-3

<u>Pipe Size</u> <u>(in.)</u>	<u>Cost</u> <u>(\$ per mile)</u>
144	1,060,000
120	770,000
96	587,000
90	545,000
84	500,000
72	375,000
60	280,000
54	250,000
48	195,000
42	155,000
36	125,000
30	100,000
24	80,000

B. Annual Costs

1. Nonfederal interest rate--4 percent.
2. Economically useful life.
 - a. Pipelines--50 years, amortization rate = 0.0465.
 - b. Pumping equipment--25 years, amortization rate= 0.0640.
3. Operation and maintenance.

a. Pipeline.

<u>Pipe Size</u> <u>(in.)</u>	<u>Annual Cost</u> <u>(\$ per mile)</u>
30 and less	75
36 to 54	100
60 to 72	150
78 to 84	200
90 to 96	250
108 to 120	300
132 to 144	350

b. Pumping plant.

- (1) All operation and maintenance (except power)--5 3/4 percent of initial capital cost per annum.
- (2) Electrical energy cost for large installations--8 mills per kw.-hr.

EXHIBIT F-4

The transmission cost calculation for Subareas O-8, T-12, and A-4 are presented for conditions of maximum economy for total annual pipeline and energy costs for both the alternate and project sources of supply.

O-8 (Oklahoma City)

From Tuskahoma Dam site (alternate source) to Oklahoma City the pipeline route is 162 miles. Oklahoma City is 612 feet above the elevation of the water supply pool in Tuskahoma Reservoir. A total supply of 146 mgd is needed to allow for transmission losses. A single line 96 inches in diameter is selected as the most economical means of transmission.

Capital Cost = \$98,920,000
 Pipeline: (\$587,000/mile) (162 miles) = \$95,000,000
 Pumping:

$$(146 \text{ mgd}) (162 \text{ miles}) (0.7 \frac{\text{ft.}}{1,000 \text{ ft.}})$$

$$(1.547 \frac{\text{cfs}}{\text{mgd}}) (5,280 \frac{\text{ft.}}{\text{mi.}})$$

$$(62.4 \frac{\text{lbs.}}{\text{ft.}^3}) \div 550 \frac{\text{ft.-lbs.}}{\text{sec.}} = 15,500 \text{ hp}$$

$$(146) (612 \text{ ft.}) (1.547) (62.4)$$

$$\div 550 = \frac{15,800 \text{ hp}}{31,300 \text{ hp}}$$

$$31,300 \text{ hp} @ \$125 / \text{hp} = \frac{3,920,000}{\$98,920,000}$$

Average Annual Cost = \$5,756,000
 (\$0.108/1,000 gals.)

Pipeline: \$95,000,000 (0.065) = \$4,420,000
 Pumping: \$3,920,000 (0.0640) = 251,000

Operation and Maintenance:

Pipeline: \$250./mile (162 mi.) = 40,500
 Pumping: \$3,920,000 (5 3/4 %) = 225,000

Average Energy Costs $\frac{1}{2}$ the 2020 requirement

$$(\frac{31,300}{2}) (24 \text{ hrs.}) (365 \text{ days}) (0.746 \frac{\text{kwh}}{\text{hp}})$$

$$(\$0.008) = \frac{820,000}{\$5,756,500}$$

EXHIBIT F-5

From Keystone Dam (project source) to Oklahoma City the pipeline route is 85 miles. Oklahoma City is 483 feet above the average elevation of the water supply pool in Keystone Reservoir. A single pipeline 96 inches in diameter is again used.

Capital Cost = \$52,470,000	
Pipeline: (\$587,000) (85) =	\$50,000,000
Pumping: ($\frac{85}{162}$) (15,500) =	8,120 hp
($\frac{483}{612}$) (15,750) =	$\frac{12,400 \text{ hp}}{20,520 \text{ hp}}$
(20,520) (\$125.) =	$\frac{2,570,000}{\$52,470,000}$

Average Annual Cost = \$3,200,800
(0.060/1,000 gals.)

Pipeline: \$50,000,000 (0.0465) =	\$2,330,000
Pumping: \$2,570,000 (0.0660) =	164,000

Operation and maintenance:

Pipeline: \$250./mile (85) =	21,300
Pumping: \$2,570,000 (5 3/4 %) =	148,000

Average Energy Cost:

($\frac{20,520}{2}$) (52.4) =	$\frac{537,500}{\$3,200,800}$
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T-12 (Dallas-Fort Worth)

The pipeline route from Boswell Dam site (the alternate source) to the upper reaches of Range Creek is 70 miles. The required 500 mgd will be lifted 295 feet from Boswell Reservoir. Three 96 inch pipelines constructed in 1990, 1995, and 2000 are selected as the most economical method of transmission.

Capital Cost for one line = \$43,420,000	
Pipeline: (\$587,000/mile) (70) =	\$41,000,000
Pumping: (166) (70) (1.0)	
(0.927) =	10,800 hp
(166) (295) (0.175) =	$\frac{8,600 \text{ hp}}{19,400 \text{ hp}}$
19,400 hp @ \$125./hp =	$\frac{2,420,000}{\$43,420,000}$

EXHIBIT F-6

Average Annual Cost for one line = \$2,729,000

Pipeline: \$41,000,000 (0.0465) = \$1,910,000

Pumping: \$2,420,000 (0.0640) = 155,000

Operation and maintenance:

Pipeline: \$250./mile (70) = 17,500

Pumping: \$2,420,000 (5 3/4 %) = 139,000

Average Energy Cost:

$$\left(\frac{19,400}{2}\right) (52.4) = \frac{507,500}{\$2,729,000}$$

The 1990 worth of three lines, discounted from the time of construction is \$6,817,000 which is equivalent to \$0.0373/1,000 gallons.

From Denison Dam (the project source) to the upper reaches of Range Creek, which flows into Lewisville Reservoir, the pipeline route is 22 miles. Total lift for the required 500 mgd is 120 feet from Lake Texoma. Three 96 inch pipelines constructed in 1990, 1995, and 2000 are again the transmission selection.

Capital Cost for one line = \$13,775,000

Pipeline: (\$587,000) (22) = \$12,900,000

Pumping:

$$\left(\frac{22}{70}\right) (10,800) = 3,390 \text{ hp}$$

$$\left(\frac{120}{295}\right) (8,600) = \frac{3,610 \text{ hp}}{7,000 \text{ hp}}$$

$$7,000 \text{ hp @ } \$125./\text{hp} = \frac{875,000}{\$13,775,000}$$

Average Annual Cost for one line = \$895,300

Pipeline: \$12,900,000 (0.0465) = \$600,000

Pumping: \$875,000 (0.0640) = 56,000

Operation and maintenance:

Pipeline: \$250./mile (22) = 5,500

Pumping: \$875,000 (5 3/4 %) = 50,300

Average Energy Cost:

$$\left(\frac{7,000}{2}\right) (52.4) = \frac{183,500}{\$895,300}$$

The 1990 worth of the three lines, discounted from the time of construction is \$2,236,000, which is equivalent to \$0.0122/1,000 gals.

A-4 (Fort Smith)

The present sources, Lake Fort Smith, Frog Bayou, and Spring Lake, which is 250 feet above Fort Smith, have a pipeline route of 22 miles. Since a 33 inch gravity line will deliver the unmet 2020 requirement of 17 mgd, only capital cost and operation and maintenance costs are needed to determine average annual cost.

Capital Cost = \$2,574,000

Pipeline: (\$117,000) (22) = \$2,574,000

Average Annual Cost = \$124,000

(\$0.02/1,000 gallons)

Pipeline: (\$2,574,000) (0.0475) =

\$122,265

Operation and maintenance:

Pipeline: (\$85.) (22) =

1,870

\$124,035

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X. BIBLIOGRAPHY

For purposes of expediency, separate bibliographies are used in this draft. In the final report, all bibliographical references appearing at the end of individual chapters or exhibits will be amalgamated in this chapter.